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REPORT OF COMPOSITE MATERIAL AND METAL COMPOSITES JOINT WORKSHO--ETC(U)

1978

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APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

REPORT OF COMPOSITE MATERIAL AND METAL COMPOSITES JOINT WORKSHOP

Washington DC

24 AND 25 AUGUST, 1978

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11 1978

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NAVAL AIR SYSTEM COMMAND

U.S. DEPARTMENT OF THE NAVY

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DEPARTMENT OF THE NAVY
NAVAL AIR SYSTEMS COMMAND
WASHINGTON, D.C. 20361

IN REPLY REFER TO
52026B/79:JAB
AUG 18 1978

From: Commander, Naval Air Systems Command
To: Distribution List

Subj: Composite Material and Metal-Composite Joint Workshop Meeting

Ref: (a) Telecons between John Birken (AIR-52026B), Robert Wallenberg (Syracuse Research Corp., Syracuse, N.Y.) and others on Distribution List

1. This is to confirm that you have been invited to attend a workshop on composite material and metal-composite material joint electromagnetic properties to be held on 24 and 25 August 1978 at the Naval Air Systems Command (NAVAIR), Washington, D. C. in Room 664 JP-2 at 0900 in accordance with reference (a).

2. The meeting is directed towards instrumentation techniques and sample holders utilized to measure convenient size composite and composite-metal joint sample electromagnetic properties. Measurements of specific electromagnetic parameters and their inter-relationships will be discussed. Participants are invited to present reviews of their own work to date and their planned future efforts. Notify John Birken, (202) 692-3935, if more than 30 minutes presentation time is required.

3. A discussion of material sample panels and joints being prepared will be held and will include the composite-metal joints being prepared by W. Gajda (Notre Dame) under Contract Number N00019-77-C-0460. Available test techniques will be analyzed with regard to how they affect the required material samples being evaluated. In particular, the methods for holding samples need to be examined for uniform testing. It is hoped that present and future users of NAVAIR-supplied samples will provide required data, dimensions, and shapes for the samples they require.

4. A viewgraph projector will be available for use in the presentation of viewfoil material. If possible, it is also suggested, but not required, that written materials be included to augment the oral presentation. Copies of viewfoil and written material will be made available to all participants.

5. If you have any questions, need further information, or wish to modify the agenda, please do not hesitate to contact Dr. Birken (NAVAIR) or Dr. Robert Wallenberg, Syracuse Research Corporation, (315) 425-5228.

R A Retta

R. A. Retta
By direction

REPORT OF
COMPOSITE MATERIAL AND METAL
COMPOSITES JOINT WORKSHOP
24 and 25 August, 1978

Hosted By

Naval Air Systems Command
Washington, D.C.

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Table of Contents

FOREWORD

The Composite Material and Metal Composites Joint Workshop was hosted by the Naval Air Systems Command (NAVAIR). Invitation to attend was provided by NAVAIR letter 52026B/78: JAB of August 18, 1978. The workshop was held at NAVAIR on 24 and 25 August, 1978.

The purposes of the workshop were:

a. The meeting is directed towards instrumentation techniques and sample holders utilized to measure convenient size composite and composite-metal joint sample electromagnetic properties. Measurements of specific electromagnetic parameters and their inter-relationships will be discussed. Participants are invited to present reviews of their own work to date and their planned future efforts.

b. A discussion of material sample panels and joints being prepared will be held and will include the composite-metal joints being prepared by W. Gajda (Notre Dame) under Contract Number N00019-77-C-0460. Available test techniques will be analyzed with regard to how they affect the required material samples being evaluated. In particular, the methods for holding samples need to be examined for uniform testing. It is hoped that present and future users of NAVAIR-supplied samples will provide required data, dimensions, and shapes for the samples they require.

This report provides copies of the visual aids used for the formal presentations.

Note: In a few instances, viewgraphs have not been included as they were found to be unsuitable for reproduction.

Composite Material and Metal Composites

Joint Workshop

24 and 25 August 1978

Chairperson: Dr. John Birken

AGENDA

Thursday, August 24, 1978

A.M.

1. J. Birken, NASC
   Overview of Joints in Composite Materials
2. W. Gajda, Notre Dame
   Materials preparation, measurements, and experimental setup at Notre Dame
3. R. Wallenberg, Syracuse Research Corporation

P.M.

4. R. Carri, Grumman Aerospace Corporation
5. J. Reardon, Naval Research Laboratory
6. E. Donaldson, EES, Georgia Tech
7. R. Stratton, Rome Air Development Center
8. D. Chang, University of Colorado

Friday, August 25, 1978

A.M.

1. S. Tompkins, NASA Langley
2. D. Swink, NSWC/Dahlgren
3. R. Prehoda, NSWC/Dahlgren

P.M.

4. G. Condon, General Electric
5. J. Roden, Syracuse Research Corporation
6. G. Becktal, NSWC/WO
7. C. Scouby, McDonnell Aircraft Corporation

8. Open Forum

Open discussion of best parameters to measure, comparison of techniques in accuracy, sample size, ease of sample preparation and ease of measurements adaptation of uniform planar jig.

Composite material sample dimension requirement from each participant. Units results will be reported in frequency of operation. NAVAIR will compile results, convert to common units compare and disseminate to all participants.

24, 25 AUGUST 1978 NAVAIR COMPOSITE JOINT WORKSHOP

NAME	ORGANIZATION	PHONE NO.
William G. Duff	Atlantic Research Corp	(703) 354-3400
N. Lynn Jarvis	Naval Research Lab.	(202)767-3550
M. Stander	NAVAIR (52032D)	(202)692-7543,5
Joseph P. Reardon	Naval Research Lab.	(202)767-2998
Harry Z. Wilson	Aerospace	(213)648-6253
C. D. Skouby	McDonnell Aircraft	(314)232-3096
Walt Gajde	Notre Dame	(219)283-3763
S.S. Tompkins	NASA - Langley	(804)827-2434
Bob Carri	Grumman Aerospace	(516)575-2754
David C. Chang	University of Colorado	(303)492-7539
Richard Hall	Naval Surface Weapons Center	(703)663-8781
Ronald Prehoda	NSWC/Dahlgren	(703)663-8781
Ernest Donaldson	Georgia Tech.	(404)894-3535
John Birken	NAVAIR	(202)692-3935
Roy Stratton	RADC	
Robert Wallenberg	Syracuse Research Corp.	(315)425-5228
Vic Mazzio	General Electric Co.	(215)962-2372
Gene Shumaker	USAF/AFFDL/FBC	(513)255-3736
G. Bechtold	NSWC/WOL	(202)394-1746
A. Somoroff	NAVAIR-320	(202)692-2515)

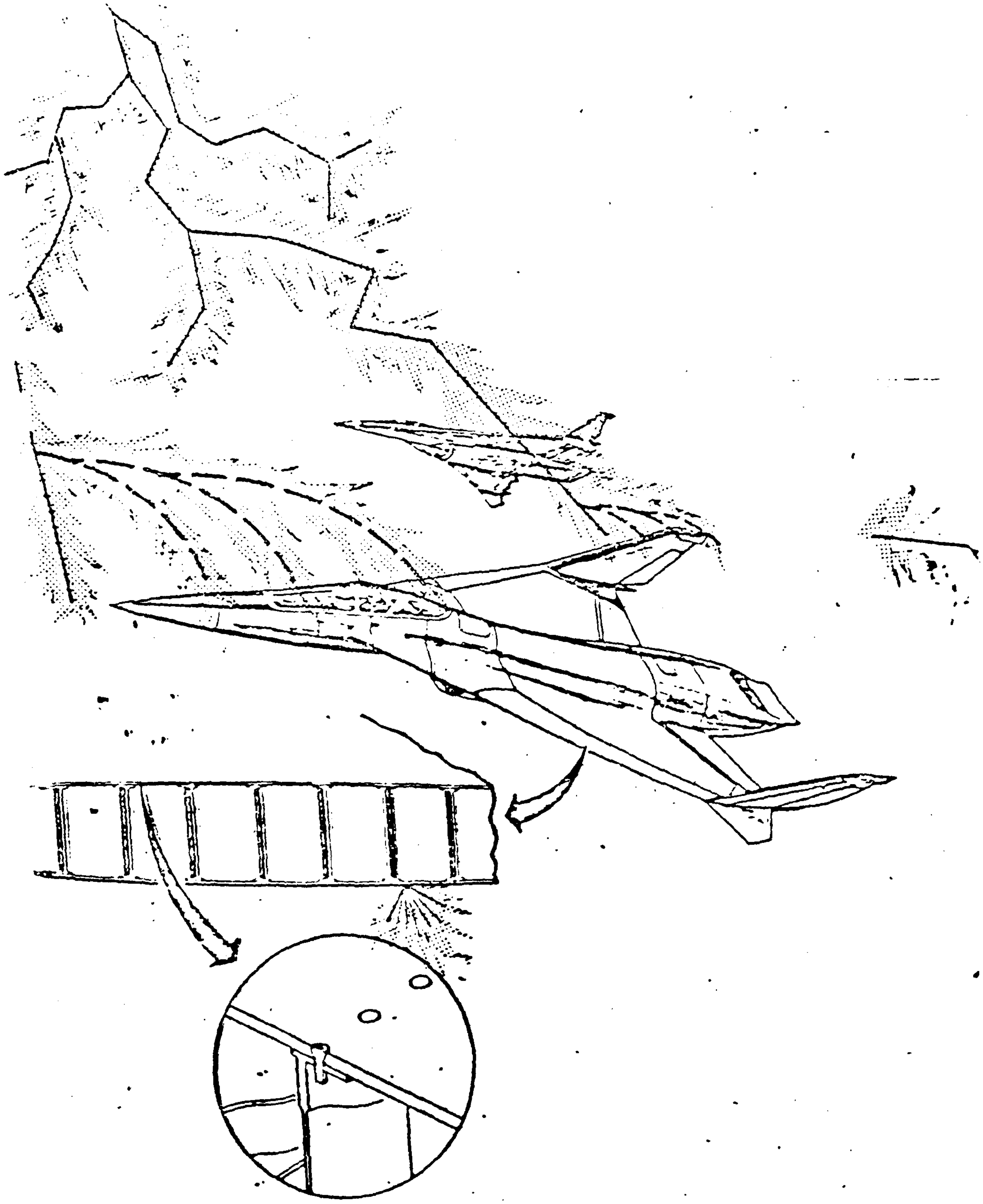
Dr. John Birken

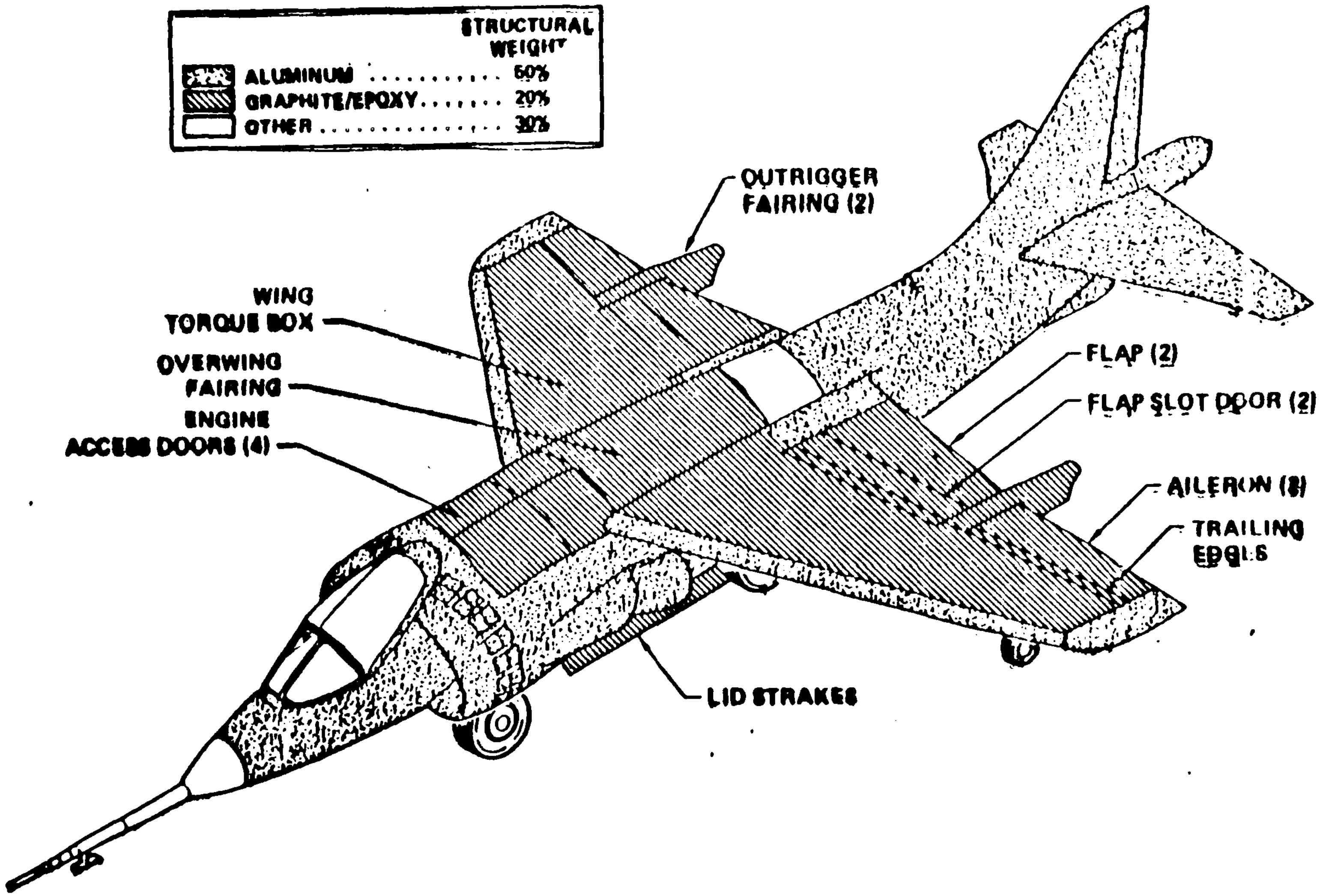
Naval Air Systems Command

Overview of Joints in Composite Materials

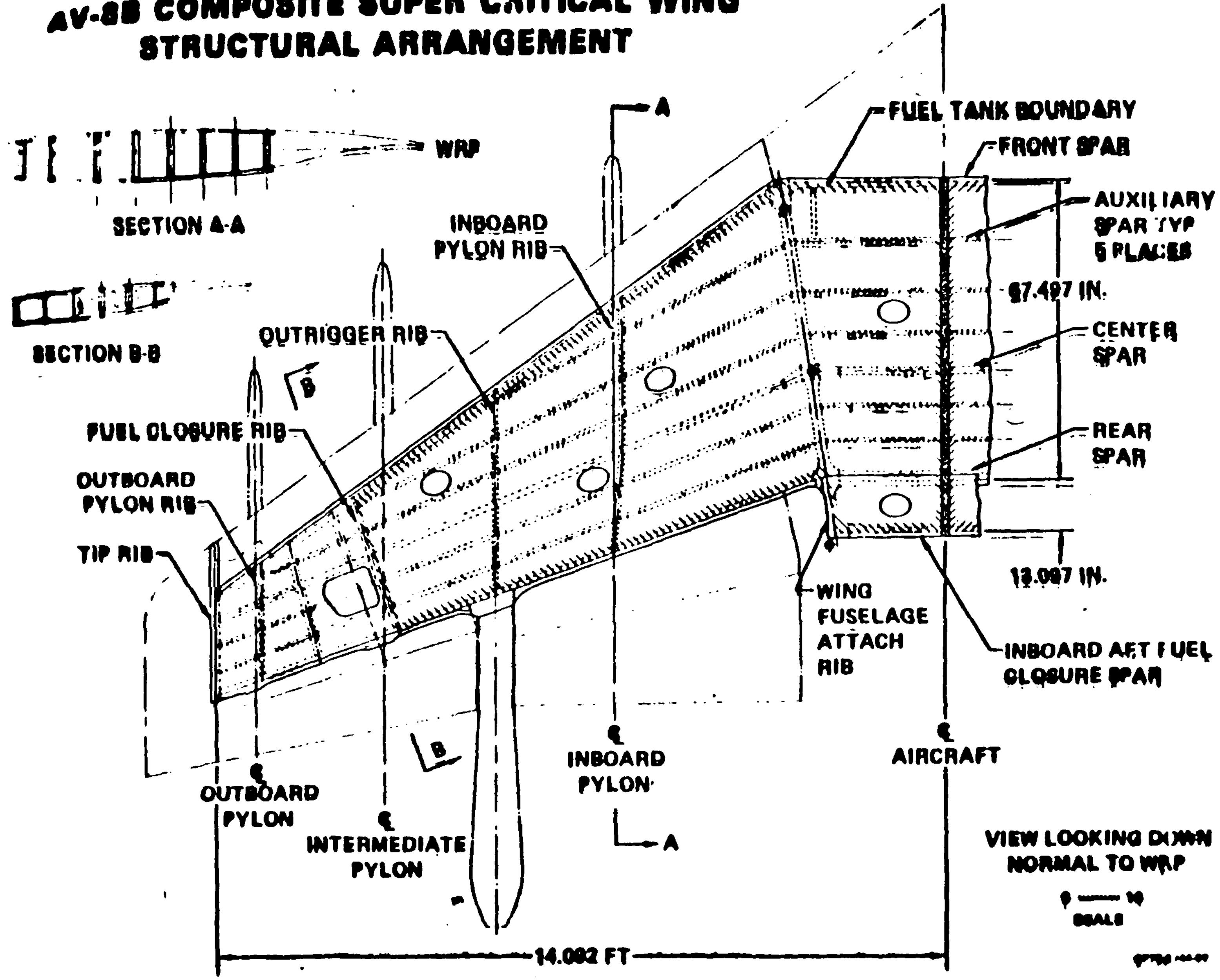
Herbler

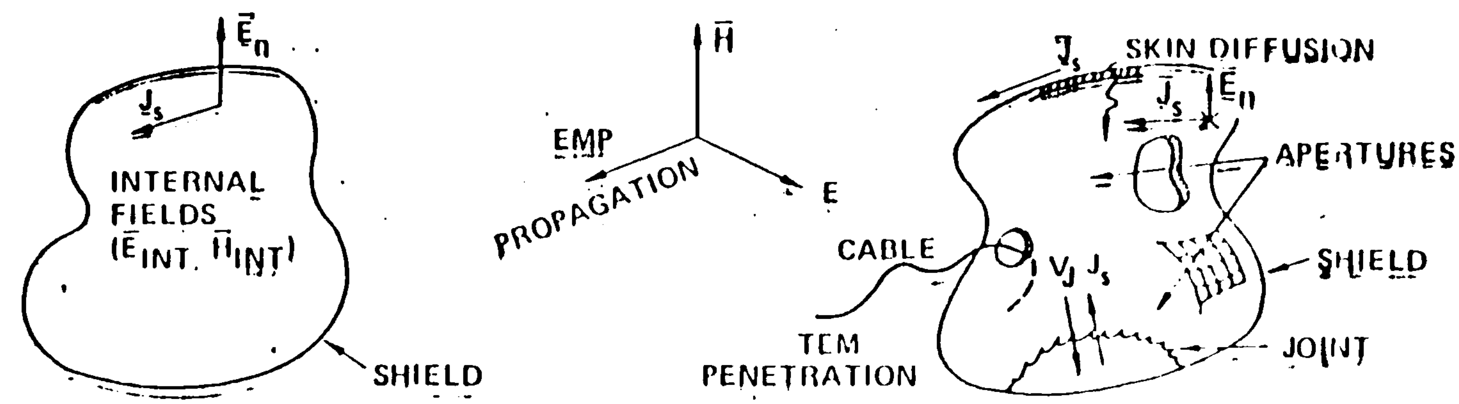
$$\int_{\text{LAB}}^{\text{FLEET}} \text{ELECTROMAGNETIC TECHNOLOGY TRANSFER}$$




STRUCTURAL WEIGHT
ALUMINUM 50%
GRAPHITE/EPOXY 20%
OTHER 30%
OUTRIGGER FAIRING (2)
WING TORQUE BOX
OVERWING FAIRING
ENGINE ACCESS DOORS (4)
FLAP (2)
FLAP SLOT DOOR (2)
AILERON (2)
TRAILING EDGES
LID STRAKES

AV-8B COMPOSITE SUPER CRITICAL WING STRUCTURAL ARRANGEMENT





Coupling mechanisms:

a) Skin diffusion (direct field propagation thru skin)
b) Apertures (antennas, windows, holes, cracks, meshes)
c) Joints and seals (door seals, skin material joints)
d) TEM coupling (insulated cable currents penetrating skin)

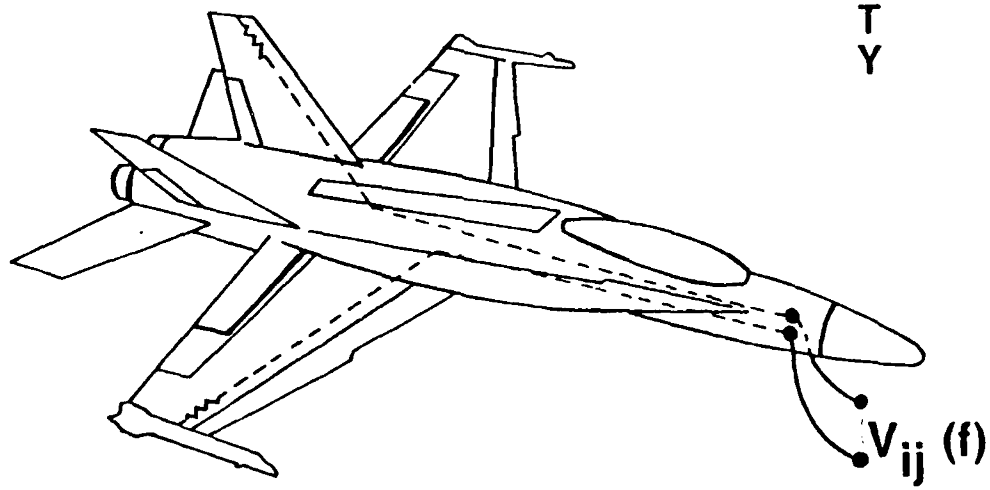
Coupling analysis procedure:

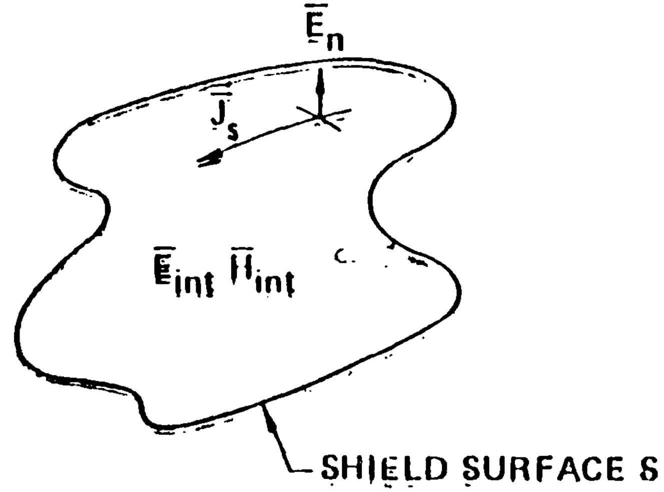
a) Calculate shield exterior surface current (J_s) and charge (normal E field E_n) due EMP
b) Calculate interior incident fields from exterior response J_s, E_n considering all coupling mechanisms.
c) Calculate interior total fields, currents, voltages, etc, from interior incident fields and geometry.

Figure 3 The EMP Coupling Problem

$$D(f) + T_1(f) + T_2(f) + T_3(f) + T_4(f) + T_5(f) = V_{ij}(f)$$

THREAT	MATERIAL SHEILDING	AIRFRAME SHAPE	JOINT LEAKAGE	CABLE SHIELDING	SUBSYSTEM SUSCEPTIBILITY	SUBSYSTEM VOLTAGE





$$\left\{\begin{matrix}\overline{E}_{int}\\ \overline{H}_{int}\end{matrix}\right\} = \oiint_S [(\overline{\overline{G}}_d + \overline{\overline{G}}_m + \overline{\overline{G}}_j) \cdot \overline{J}_s + \overline{\overline{G}}_p \cdot \overline{E}_n] ds$$

Skin diffusion:

$\overline{\overline{G}}_d \sim z_{sd}$ (open circuit diffusion transfer impedance: ohms/square)

Distributed aperture coupling (meshes)

$\overline{\overline{G}}_p \sim P$ (surface electric polarizability: farads

$\overline{\overline{G}}_m \sim M$ (surface magnetic polarizability: meters)

Joint coupling

$\overline{\overline{G}}_J \sim \dfrac{1}{Y_J}$; Y_J (joint admittance per unit of joint width or run: mhos/meter)

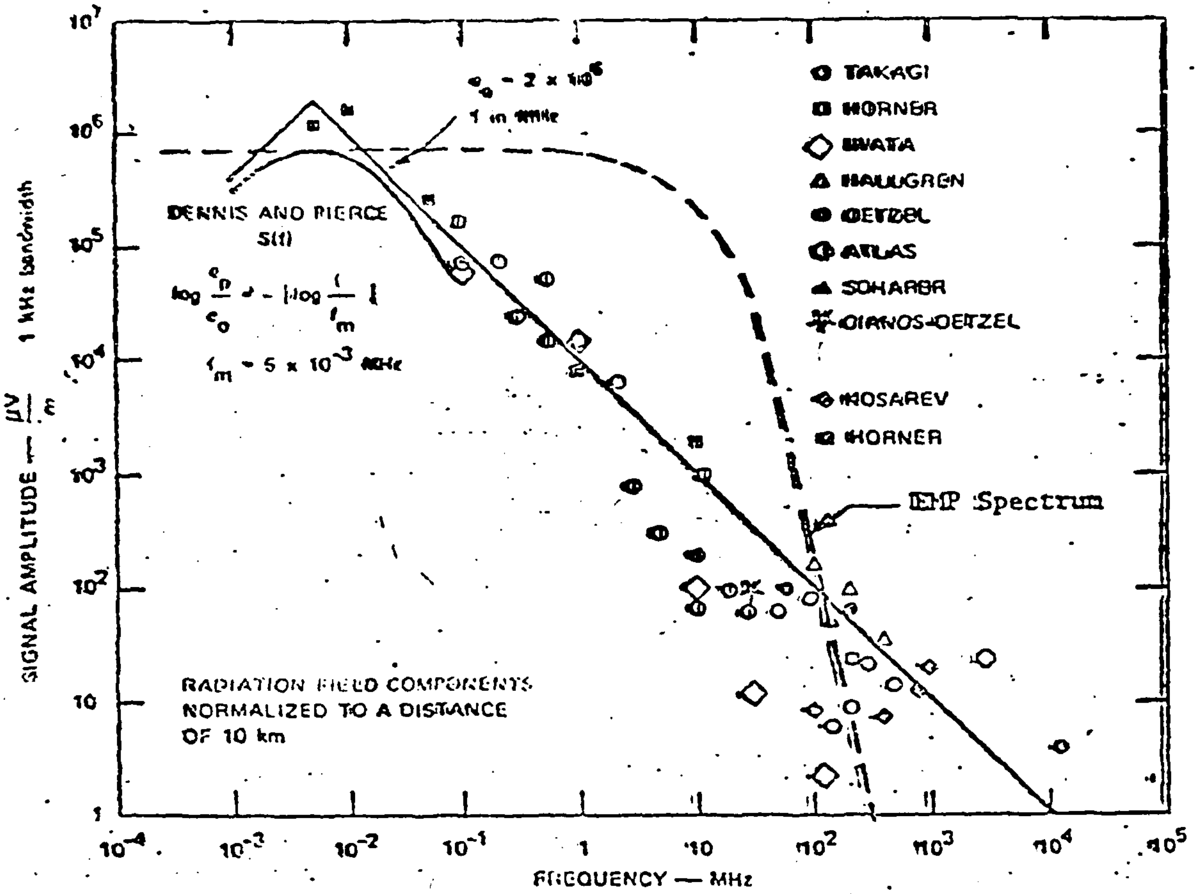
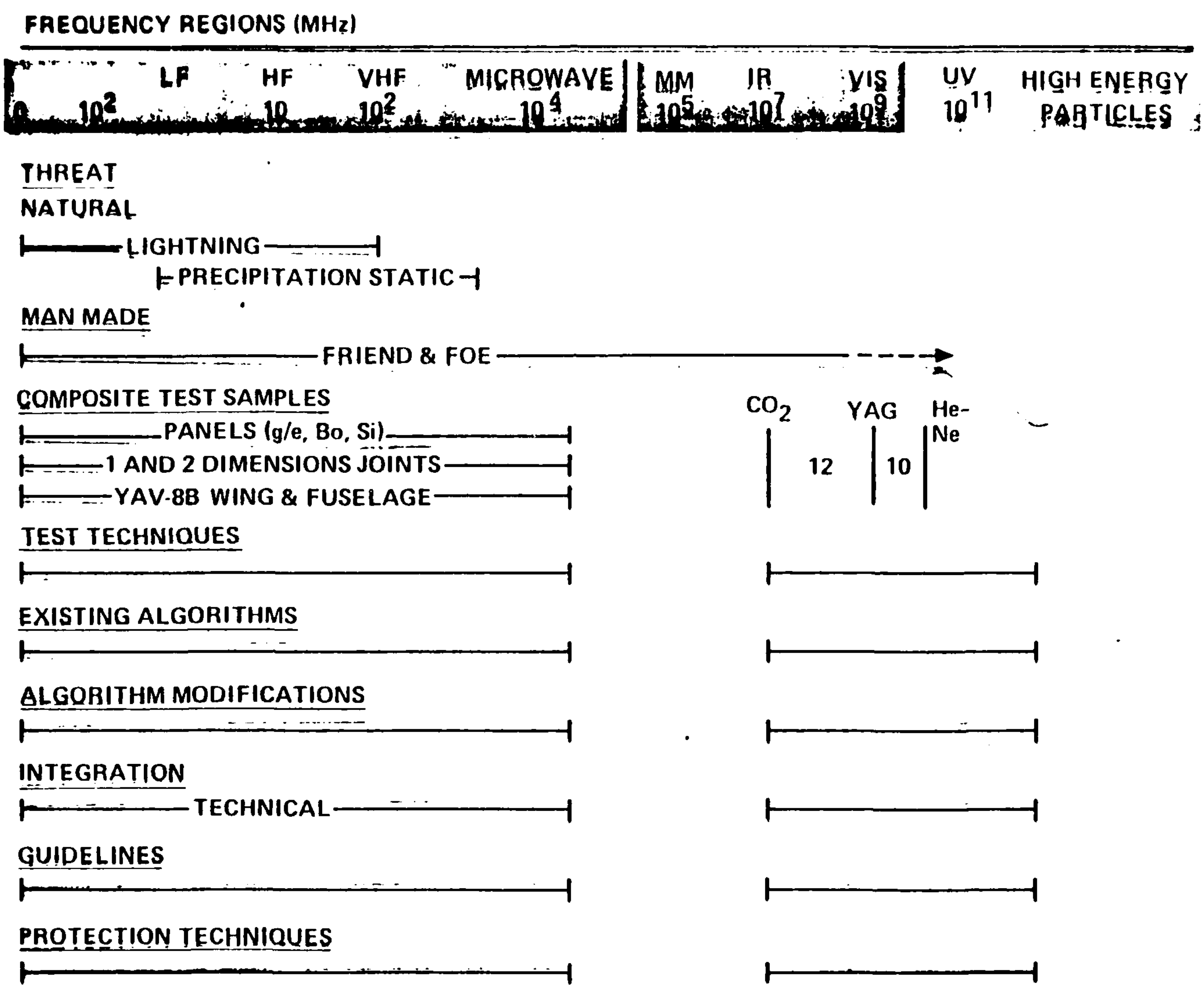


Figure 1.3.3 Peak Received Amplitude for Signals Radiated by Lightning Compared to an EMP Spectrum at 10 km

(Lightning Spectrum after Cianos & Pierce)

F.g. 3

SYSTEMATIC EM DESIGN AND SYNTHESIS



	Graphite/Epoxy	Boron/Epoxy	Kevlar
Permeability μ_R	1	1	1
Permittivity μ_R	Indeterminant	5.6	3.6
DC Conductivity (mhos/m)			
longitudinal σ_L	$2(10^4)$	30	$6(10^{-9})$
transverse σ_T	100	$2(10^{-8})$	$6(10^{-9})$
Anisotropy Ratios (σ_L/σ_T)	200	$1.5(10^9)$	1
High Field Thresholds			
longitudinal			
E_{NL} (volts/m)	250	not	not
J_{NL} (amps/m^2)	$4(10^5)$	measured	measured
tranverse			
E_{NL} (volts/m)	4000	not	not
J_{NL} (amps/m^2)	$1(10^4)$	measured	measured

SUMMARY OF ELECTRICAL PROPERTIES OF MEASURED COMPOSITES

COMPOSITE MATERIAL FUNDAMENTAL

ELECTRICAL PROPORTIES

CONDUCTIVITY $\rho(f)$

PERMEABILITY $\mu(f)$

PERMITTIVITY $\epsilon(f)$

VARY WITH FREQUENCY

Table VI

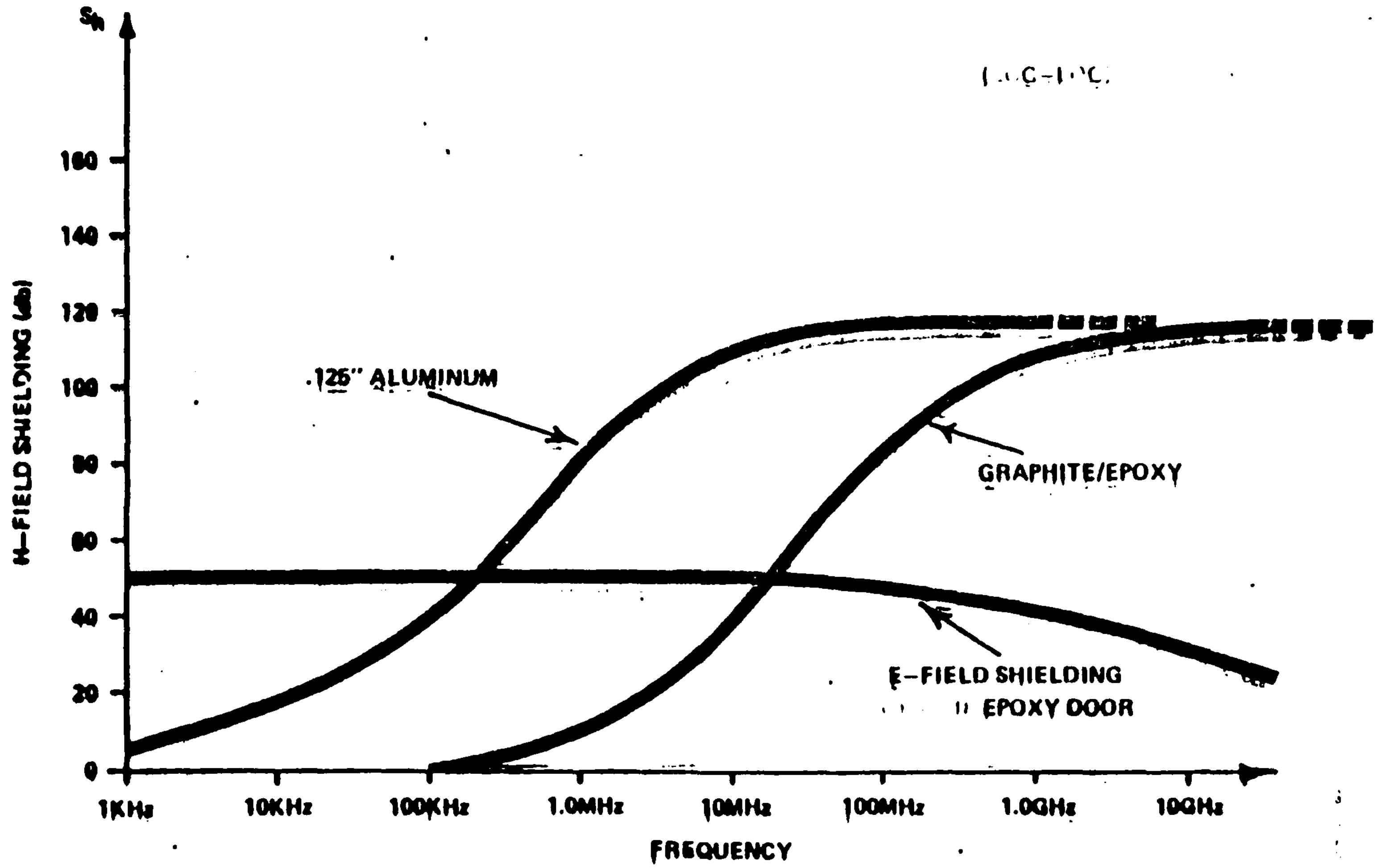
SUMMARY OF FORMULAS FOR SHIELDING EFFECTIVNESS

$SE = A + R + C$ (106)

r = distance from source to shield, meters
μ_r = relative permeability
g_r = conductivity relative to copper
f = frequency, Hz.

Source	Attenuation A, dB	Reflection Loss R, dB	Correction Term C, dB
Plane Wave $r \geq \frac{kL^2}{\lambda}$ (140) and Table V or $r \geq 2\lambda$ (dipole)	$131.4 \ell \sqrt{f\mu_r g_r}$ (173)	$168 + 20 \log \sqrt{\frac{g_r}{f\mu_r}}$ (183)	$\rho = 4 \frac{(1-m^2)^2 - 2m^2 - j2\sqrt{2}m(1-m^2)}{[(1+\sqrt{2}m)^2 + 1]^2}$ (187) $m = 9.27 \times 10^{-10}\sqrt{\frac{f\mu_r}{g_r}}$ (188) $C = 20 \log \left\| 1-10^{-\frac{A}{10}}(\cos 0.23A - j\sin 0.23A)\right\|$ (189)
Loop, Near Field $r \leq \frac{\lambda}{2\pi}$	$131.4 \ell \sqrt{f\mu_r g_r}$ (173)	$-9 + 20 \log \left[\frac{3.32 \times 10^{-2}}{r}\sqrt{\frac{\mu_r}{f g_r}} - 1 + 15.1 r\sqrt{\frac{f g_r}{\mu_r}}\right]$ (194)	$\rho = 4 \frac{(1-m^2)^2 - 2m^2 - j2\sqrt{2}m(1-m^2)}{[(1-\sqrt{2}m)^2 + 1]^2}$ (196) $m = \frac{4.7 \times 10^{-2}}{r}\sqrt{\frac{\mu_r}{f g_r}}$ (197) $C = 20 \log \left\| 1-\rho 10^{-\frac{A}{10}}(\cos 0.23A - j\sin 0.23A)\right\|$ (179)
Electric Dipole, Near Field $r \leq \frac{\lambda}{2\pi}$	$131.4 \ell \sqrt{f\mu_r g_r}$ (173)	$322 + 20 \log \frac{1}{r}\sqrt{\frac{g_r}{\mu_r f}}$ (200)	$\rho = 4 \frac{(1-m^2)^2 - 2m^2 - j2\sqrt{2}m(1-m^2)}{[(1-\sqrt{2}m)^2 + 1]^2}$ (203) $m = 0.205 \times 10^{-16} r \sqrt{\frac{\mu_r f^3}{g_r}}$ (204) $C = 20 \log \left\| 1-\rho 10^{-\frac{A}{10}}(\cos 0.23A - j\sin 0.23A)\right\|$ (179)

MAGNETIC SHIELDING VS. FREQUENCY FOR SEVEN LAYER GRAPHITE/EPOXY OVERLAY AND ALUMINUM



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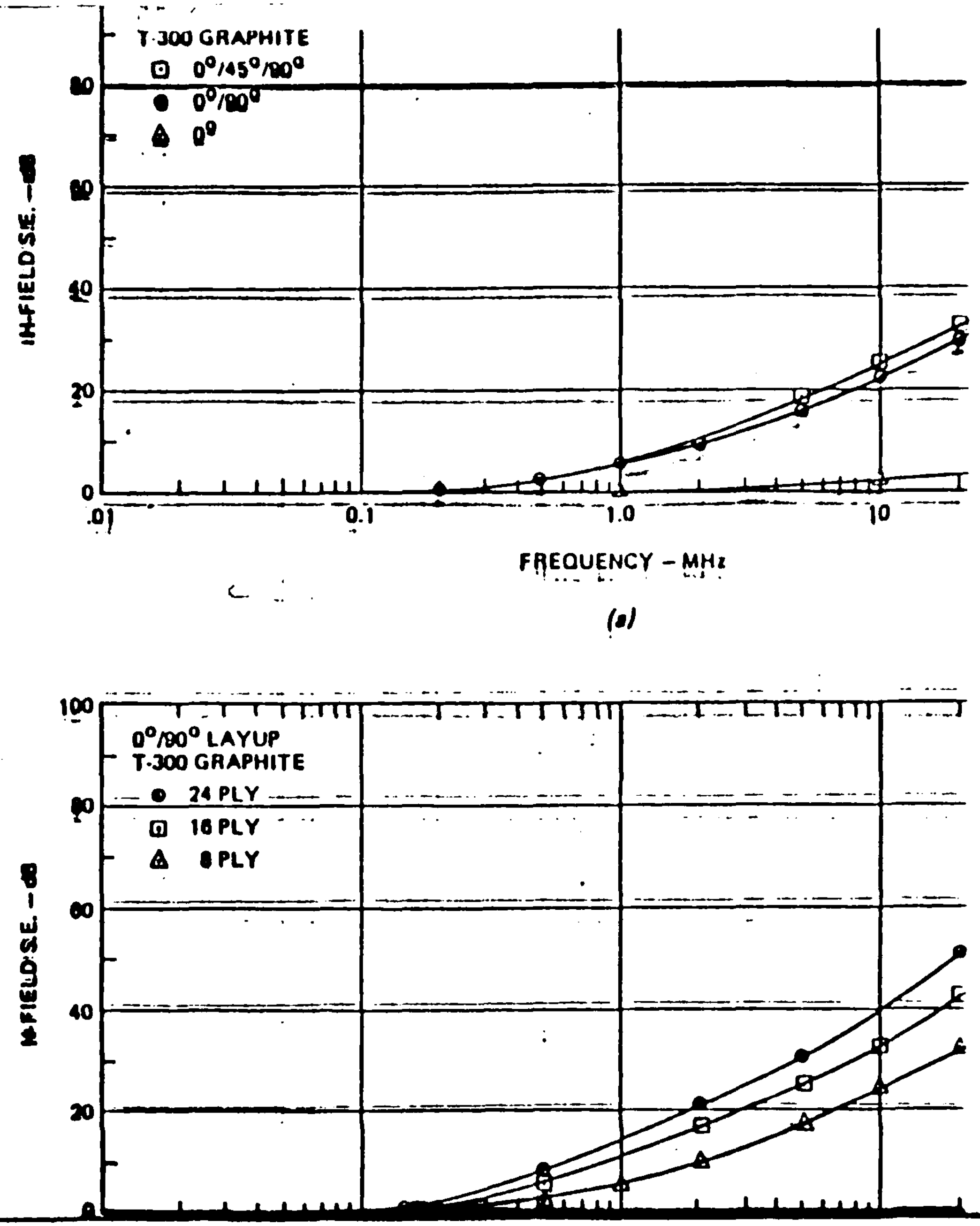
NASA LANGLEY RESEARCH CENTER



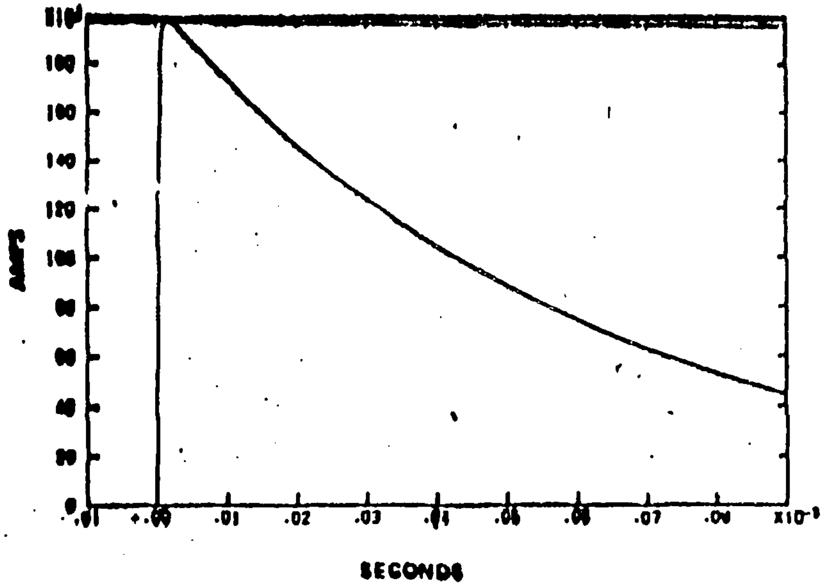
T-300 GRAPHITE
$0^{o}/45^{o}/90^{o}$
$0^{o}/90^{o}$
0^{o}
H-FIELD S.E. — dB
80
60
40
20
0
.01
0.1
1.0
10
FREQUENCY — MHz
(a)
$0^{o}/90^{o}$ LAYUP
T-300 GRAPHITE
24 PLY
16 PLY
8 PLY
H-FIELD S.E. — dB
100
80
60
40
20
0

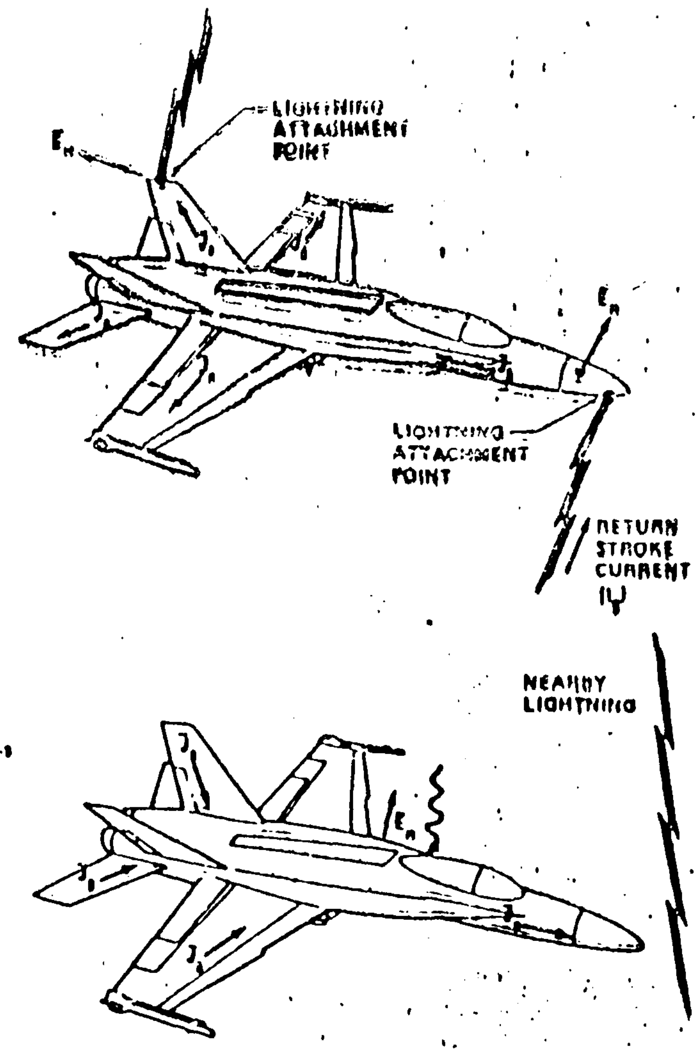
TABLE 11 z_s OF COMPOSITES, COATINGS AND COATED COMPOSITES

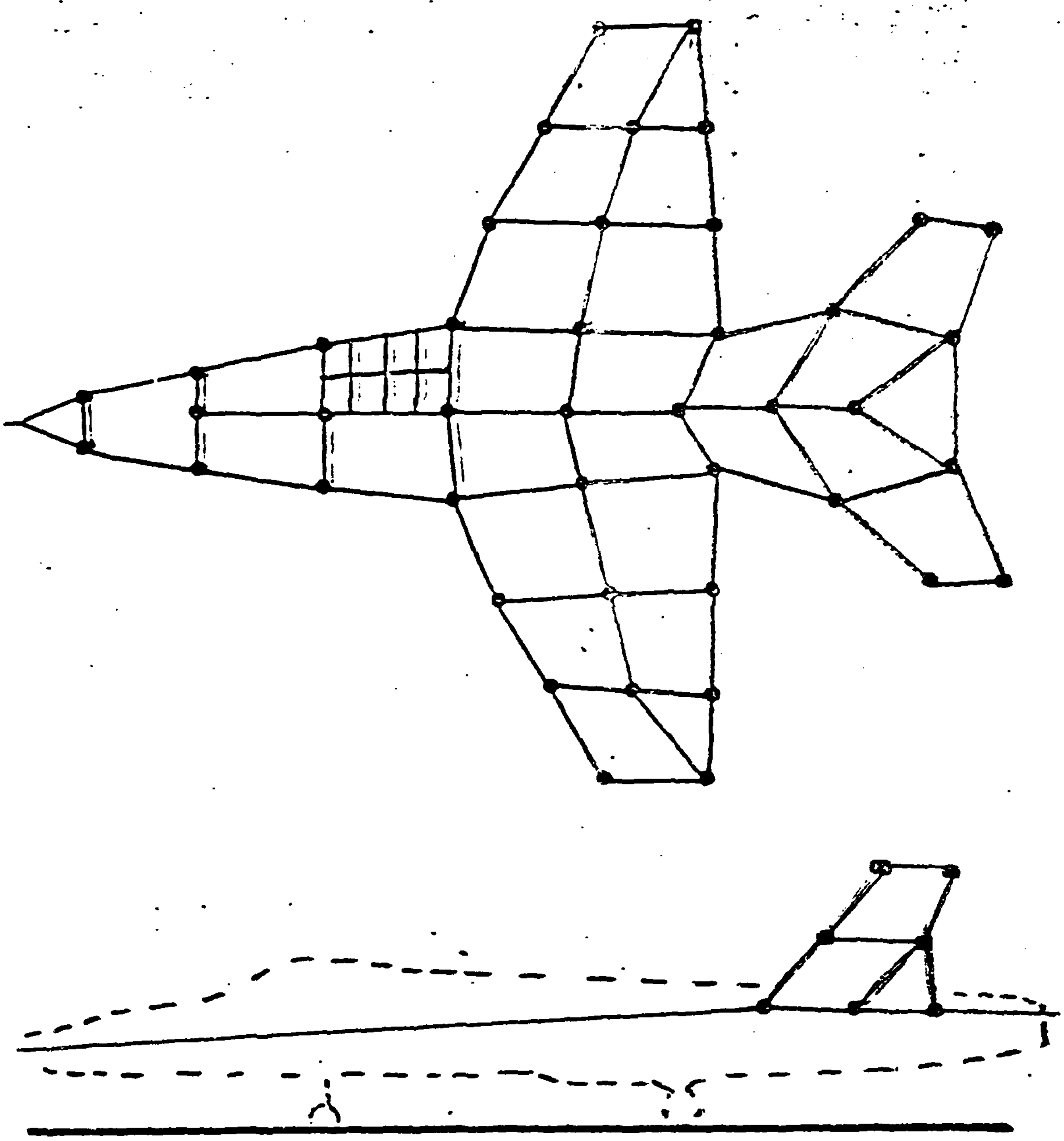
z_s (dB BELOW 1 OHM)

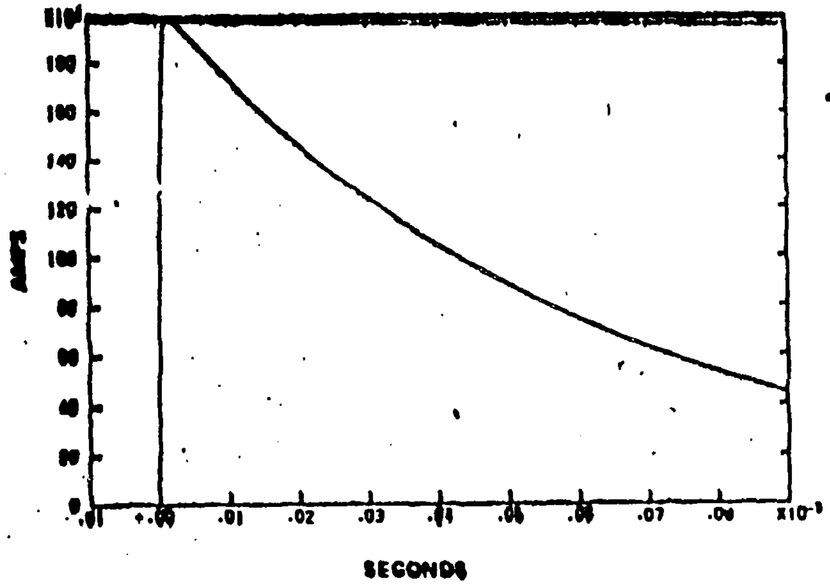
MATERIAL	FREQUENCY (MHz) .01	.1	1	10	100
64 Mil Aluminum*	-97	-122.6	-225	-571	-850
8 Ply T300 Graphite	-27	-27	-27	-27.5	-33.5
Ply T300 Graphite	-35.8	-35.8	-36	-45	-102
2 Ply Hts Graphite	-30	-30	-30	-32	-52
24 Ply Rig 5505 Boron*	—	—	—	-8.1	-18.1
SCREENS					
18 Mesh Aluminum	-56	-56	-54	-36	-17
Mesh Aluminum	-60.5	-61	-63	-57.7	-44.4
0 Mesh Aluminum	-67.4	-67.4	-58.2	-60.4	-54.9
200 Mesh Aluminum	-47.7	-47.7	-48	-48.3	-53
Mesh Phosphor Bronze	-52	-51	-51.5	-52.5	-47
0 Mesh Phosphor Bronze	-45.6	-45.6	-46	-47	-45.5
120 Mesh Phosphor Bronze	-47.4	-47.4	-47.4	-48	-53
4 Mesh Steel-27	-50	-48	-42	-27	-7
FOILS					
7 Mil Copper	-74	-74	-74.2	-83	-133
Mil Aluminum	-64	-64	-64.5	-69.5	-96.5
1 Mil Aluminum	-58	-58	-58	-59	-66.4
Mil Conetic Foil	-48	-62	-130*		
COATED COMPOSITES					
Ply T300 + 2 Mil Aluminum	-64	-64	-71.4	-95.4	-195*
Ply T300 + 40 Mesh Aluminum	-60.5	-60.5	-64.4	-81.4	-143*
24 Ply T300 + 1 Mil Aluminum	-58	-58	-63.4	-84.9	-164*
Ply T200 + 120 Mesh Aluminum	57.4	57.4	-59.4	-81.4	-153*
24 Ply T300 + 80 Mesh Phosphor Bronze	-52	-52	-64.9	-75.4	-145*
Ply T300 + 120 Mesh Phosphor Bronze	-49	-49	-51.5	-72.5	-151*
12 Ply Hts + 120 Mesh Phosphor Bronze	-47.4	-47.4	-49.5	-60	-97
Ply Hts + 100 Mesh Phosphor Bronze	-48.7	-48.7	-49.3	-59.1	-91

*ALCULATED


AMPS
SECONDS
x10^-3


LIGHTNING ATTACHMENT POINT
LIGHTNING ATTACHMENT POINT
RETURN STROKE CURRENT
NEARBY LIGHTNING




AMPS
SECONDS
X10⁻³

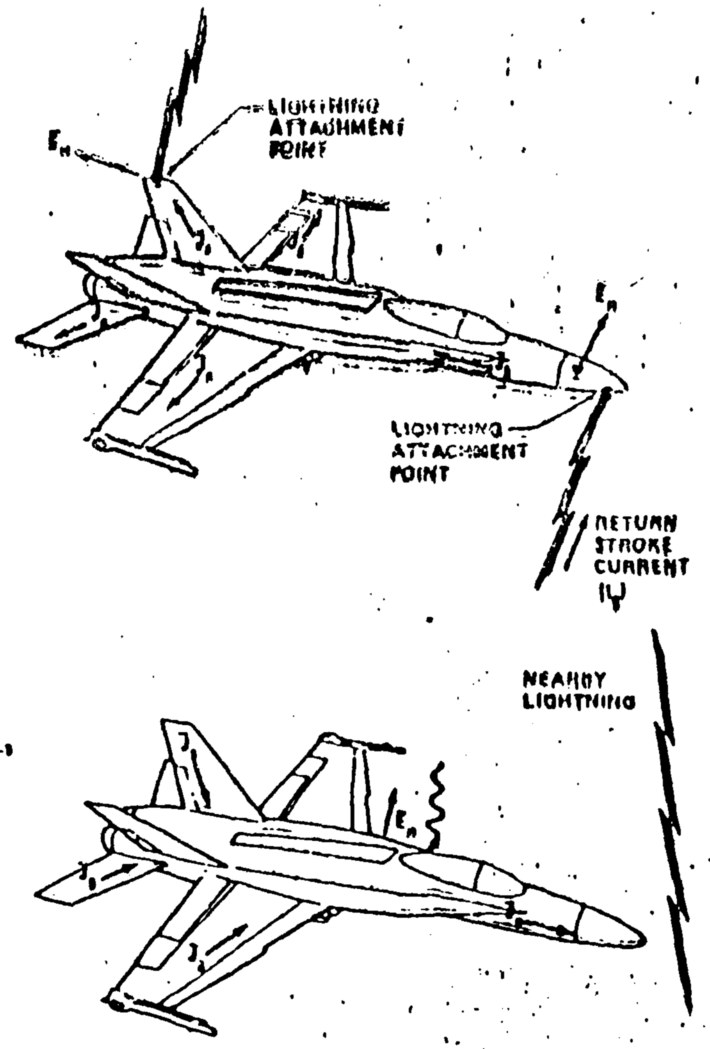

LIGHTNING ATTACHMENT POINT
LIGHTNING ATTACHMENT POINT
RETURN STROKE CURRENT
NEARBY LIGHTNING

Table 5.—Peak Transients on Nose/Tail Wire

NOTE: Values are given for open circuit voltage (V_{oc}) and short-circuit current (I_{sc}) from wire to structural ground.

Threat		Transient source	All metal (closed cockpit)	All metal (open cockpit)	All composite	Composite tail		Composite access doors	
						Diffusion	Joint	Diffusion	Joint
LEMP	Nose/tail attachment	V_{oc}, V	10.1	-4500	-32000	-28000	2100	-5500	0400
		I_{sc}, A	0.3	-67	-1100	-750	20	-180	48
	Nearby strike	V_{oc}, V	*	-90	250	-54	21	-130	28
		I_{sc}, A	*	-1.3	8.2	-1.8	0.70	-4.5	0.95
NEMP	E∥ fuselage	V_{oc}, V	*	2200	102	15	-37	68	-19
		I_{sc}, A	*	28	1.5	0.15	-0.37	0.83	-0.22
	E⊥ fuselage	V_{oc}, V	*	–	36	–	–	–	–
		I_{sc}, A	*	–	0.47	–	–	–	–

*Less than 0.1 volt (or amp)

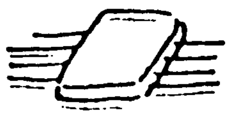
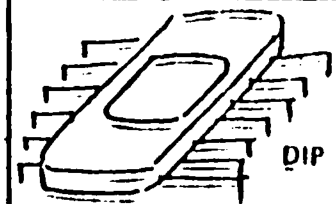
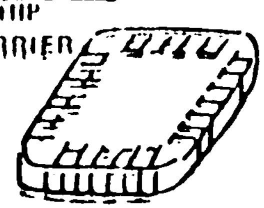
Table 6.—Peak Transients on Nose/Wing Tip Wire

*Less than 0.1 volt (or amp)

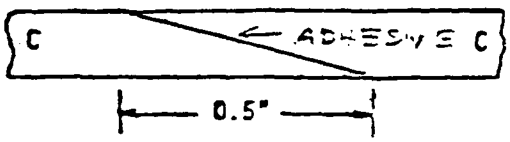
Note: Values are given for open circuit voltage (V_{oc}) or short circuit current (I_{sc}) from wire to structural ground.

Threat		Transient source	All metal (closed cockpit)	All composite	Composite wing	
					Diffusion	Joint
LEMP	Nose/tail attachment	V_{oc}, V	-2.1	-6500	–	–
		I_{sc}, A	-0.1	-220	–	–
	Nose/wing tip attachment	V_{oc}, V	-5.4	-17000	-11300	2800
		I_{sc}, A	-0.2	-550	-370	95
NEMP	E∥ fuselage	V_{oc}, V	*	84	–	–
		I_{sc}, A	*	1.3	–	–
	E⊥ fuselage	V_{oc}, V	*	76	88	-24
		I_{sc}, A	*	1.1	1.0	-0.33

TECHNOLOGY TRENDS

TUBES	DISCRETE TRANSISTORS	INTEGRATED CIRCUITS (IC)	LARGE SCALE INTEGRATED CIRCUITS (LSI)	VERY LARGE SCALE INTEGRATED CIRCUITS (VLSI)
	 TO-5	FLAT PACK 	 DIP	CHIP CARRIER 
250V 1 WATT/DEVICE	12V–24V 10^{-1}–10^{-2} WATTS/DEVICE	5V–12V 10^{-2}–10^{-3} WATTS/TRANS	5V–7V 10^{-3}–10^{-4} WATTS/TRANS	1.5V–3V 10^{-5}–10^{-6} WATTS/TRANS
GLASS/ METAL/ CERAMIC	METAL/ CERAMIC	METAL/ CERAMIC/ EPOXY	METAL/ CERAMIC/ EPOXY	CERAMIC/ EPOXY
F-9	F-4	F-14	F-18	VSTOL
ALUMINUM	ALUMINUM	ALUMINUM/TITAN	GRAPHITE-EPOXY ALUMINUM	GRAPHITE-EPOXY ?
PRE-1950's	1950's	1960's	1970's	1980's

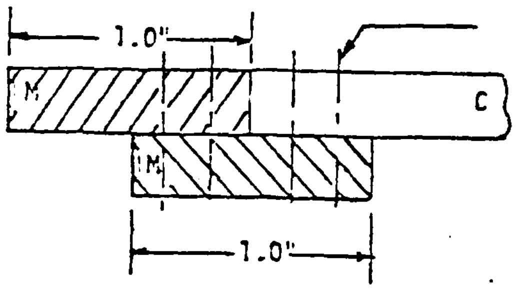
SKIRT JOINT

1 

CYLINDER WAS FABRICATED EXTRA LONG, CUT, MACHINED AND SECONDARILY BONDED WITH EA-934 ADHESIVE.

$Y_J|_{0-100\,Hz} \sim 2 \frac{MHOS}{Meter}$

RIVITED JOINT

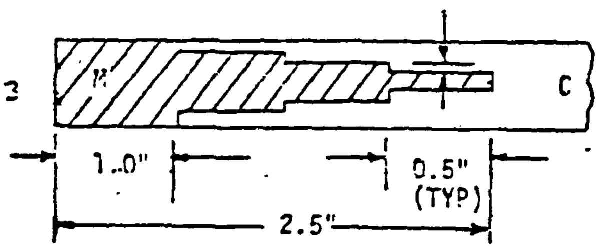
2 

1/8 DIA RD.HD. RIVET C TO M
1/8 DIA BOLT M. TO M.

CYLINDER CENTER TOWARDS BOTTOM OF PAGE. METAL RINGS FABRICATED FROM ALUMINUM SHEET, CUT, ROLLED AND WELDED. THE RIVETS OR BOLTS WERE PLACED IN A CIRCUMFERENTIAL ROW APPROXIMATELY ONE INCH APART AND ALTERNATING 1/8 INCH TO EITHER SIDE OF THE CIRC. CTR LINE.

$Y_J|_{0-100\,Hz} \sim 1.5 \frac{MHOS}{METER}$

DOUBLE STAIRCASE JOINT

3 

FIRST THREE STEPS (4 PLY PER STEP) WERE PRECURED (COMPACTED), EA-934 APPLIED TO SANDED COMPOSITE STEPS, AND THEN LONGITUDINALLY SLIT METAL RING MANEUVERED INTO PLACE. REMAINING COMPOSITE STEPS WERE APPLIED TO EA-934 COATED METAL RING IN PLACE. METAL RING WAS FABRICATED FROM 2024 ALUMINUM.

$Y_J|_{0-100\,Hz} \sim 2.30 \frac{MHOS}{METER}$

Figure 84.—Structural Joints

	TAIL							WING				ACCESS DOORS					
		JOINT							JOINT				JOINT				
	COMP.	6	9	15	60	90	230	COMP.	5	15	50	COMP.	4	9	15	60	90
LIGHTNING	22K		3.5K	2.1K		350		11K	8.5K	2.8K	850	5.5K		2.4K	1.4K		240
NEMP	15	90		37	9		2.4	88	72	25	7.2	68	70		19	7	

Y_J = 15 mho/m FOR JOINT NO. 5
= 230 mho/m FOR JOINT NO. 4

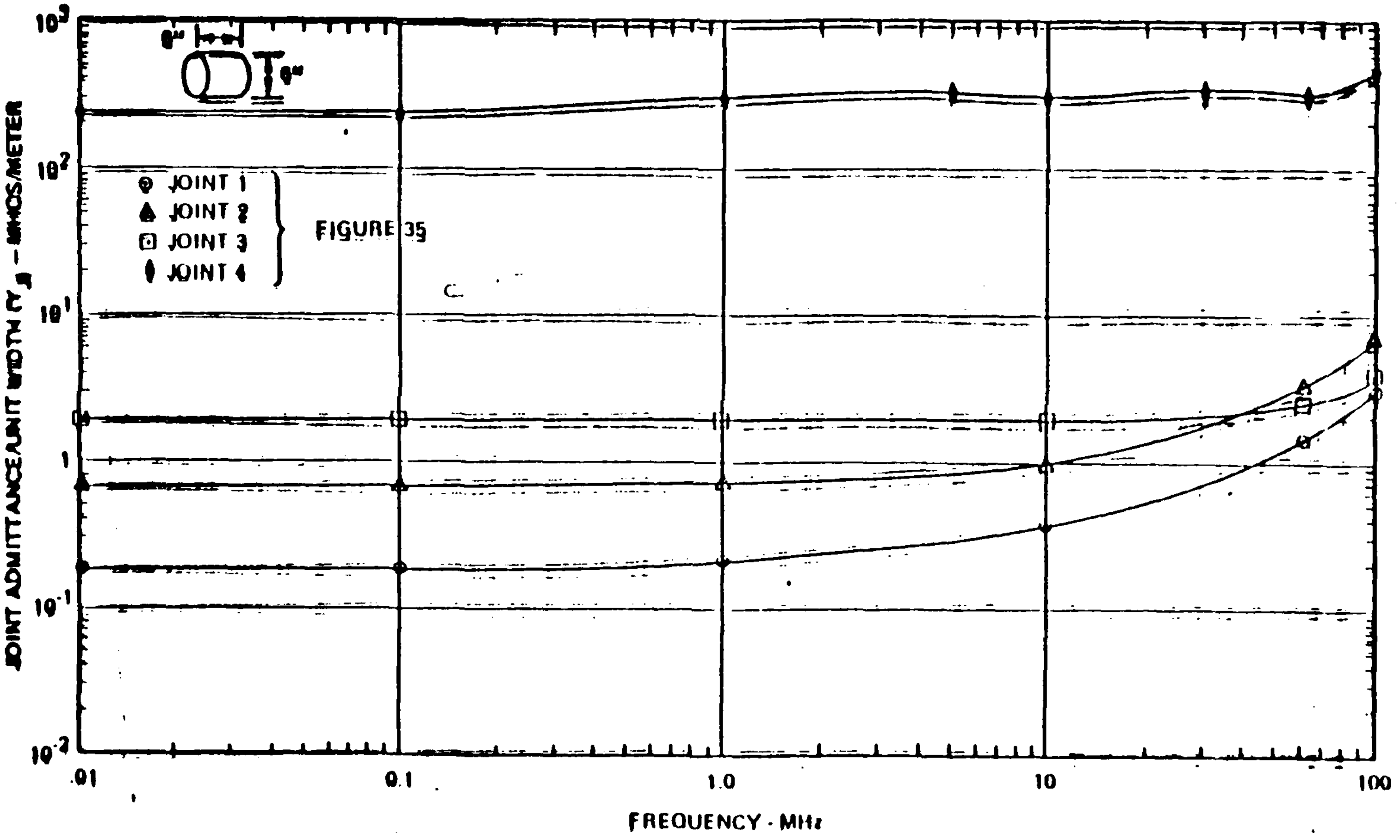


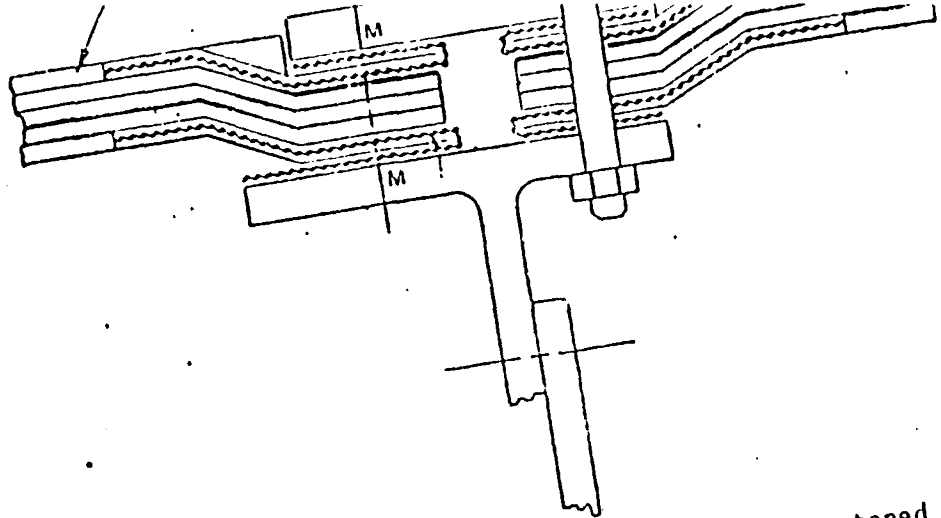
Figure 96 *Measured Joint Admittance of Structural Joints*

Table 7.—Peak Open Circuit Voltages for Composite Structures Versus Joints

	Tail				Wing				Access doors			
	Through composite contribution	Joint contribution			Through composite contribution	Joint contribution			Through composite contribution	Joint contribution		
		#1	#2	#3		#1	#2	#3		#1	#2	#3
LEMP	72 KV	116 KV	2.1 KV	0.14 KV	11 KV	21 KV	2.8 KV	0.18 KV	5.5 KV	11 KV	1.4 KV	0.09 KV
NEMP	115 V	1280 V	37 V	2.4 V	68 V	190 V	25 V	1.6 V	68 V	140 V	19 V	1.2 V

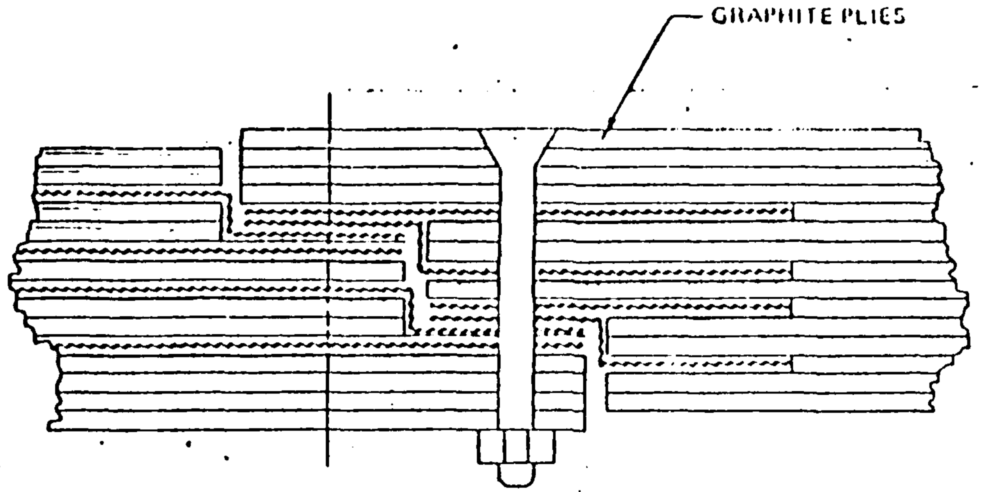
Y_J = 2 mho/m for joint no. 1
= 15 mho/m for joint no. 2
= 230 mho/m for joint no. 3

Note: The wire circuits are identical to those described for the previous calculations



Folded Multiple Screens, Mechanically Fastened
Joint with Metal Doublers

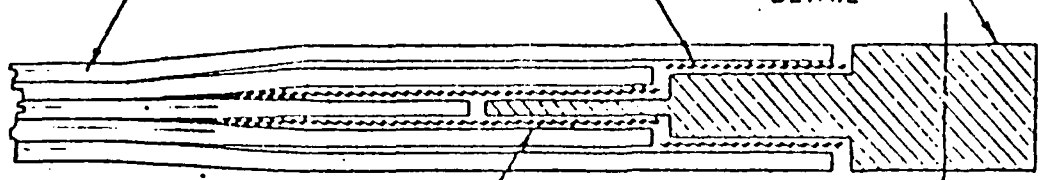
- TYPICAL APPLICATION - SKIN SPLICE AT LONGERON OR SPAR CAP
- LOAD TRANSFER MECHANISM - TITANIUM OR ALUMINUM SPLICE PLATES
- POTENTIAL ADVANTAGE - EASIER FABRICATION DUE TO THE EXTERNAL SCREEN PLIES



Multiple Exposed Screen, Mechanically Fastened Stepped Lap Joint

MULTIPLE EXPOSED SCREEN, MECHANICALLY FASTENED STEPPED LAP JOINT

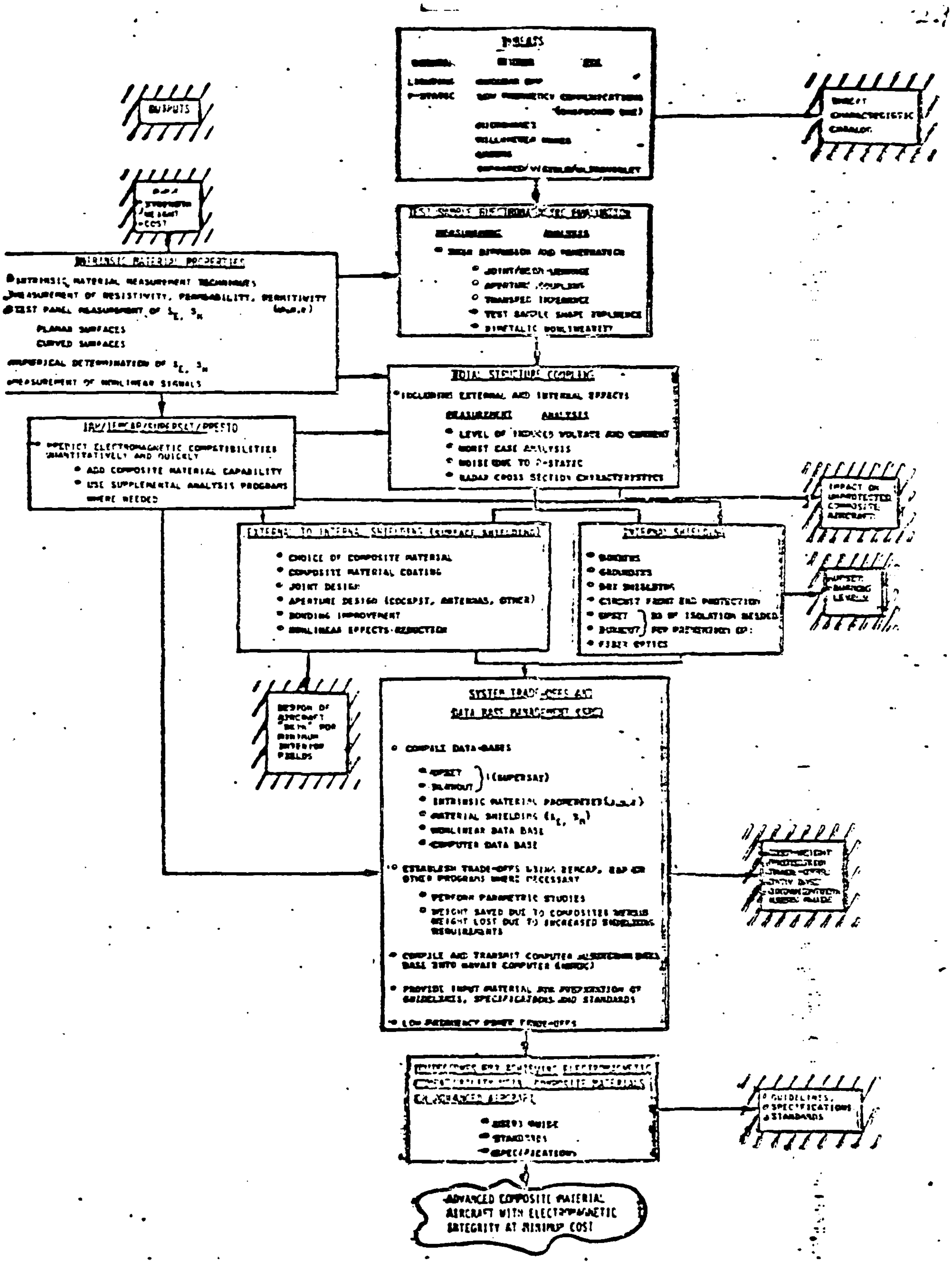
- o TYPICAL STEPPED LAP JOINT
- o LOAD TRANSFER MECHANISM - MECHANICAL FASTENERS
- o POSSIBLE ADVANTAGE - POSITIVE PRESSURE IN SCREEN INTERFACE AREA



Center Screen Stepped Lap Composite to Metal Joint

CENTER SCREEN STEPPED LAP COMPOSITE TO METAL JOINT

- TYPICAL WING STEPPED JOINT
- LOAD TRANSFER MECHANISM - ADHESIVE BOND



OUTPUTS
STRENGTH
WEIGHT
COST
INTRINSIC MATERIAL PROPERTIES
INTRINSIC MATERIAL MEASUREMENT TECHNIQUES
MEASUREMENT OF RESISTIVITY, PERMEABILITY, PERMITIVITY
TEST PANEL MEASUREMENT OF S_E, S_H
PLANAR SURFACES
CURVED SURFACES
EMPIRICAL DETERMINATION OF S_E, S_H
MEASUREMENT OF NONLINEAR SIGNALS
TEST SAMPLE ELECTROMAGNETIC EVALUATION
MEASUREMENT
ANALYSIS
DIFFUSION AND PENETRATION
JOINT/SEAM LEAKAGE
APERTURE COUPLING
TRANSFER IMPEDANCE
TEST SAMPLE SHAPE INFLUENCE
BIMETALLIC NONLINEARITY
TOTAL STRUCTURE COUPLING
INCLUDING EXTERNAL AND INTERNAL EFFECTS
MEASUREMENT
ANALYSIS
LEVEL OF INDUCED VOLTAGE AND CURRENT
WORST CASE ANALYSIS
NOISE DUE TO P-STATIC
RADAR CROSS SECTION CHARACTERISTICS
PREDICT ELECTROMAGNETIC COMPATIBILITIES QUANTITATIVELY AND QUICKLY
ADD COMPOSITE MATERIAL CAPABILITY
USE SUPPLEMENTAL ANALYSIS PROGRAMS WHERE NEEDED
IMPACT ON UNPROTECTED COMPOSITE AIRCRAFT
EXTERNAL TO INTERNAL SHIELDING (SURFACE SHIELDING)
CHOICE OF COMPOSITE MATERIAL
COMPOSITE MATERIAL COATING
JOINT DESIGN
APERTURE DESIGN (COCKPIT, ANTENNAS, OTHER)
BONDING IMPROVEMENT
NONLINEAR EFFECTS REDUCTION
INTERNAL SHIELDING
CIRCUIT FRONT END PROTECTION
FIBER OPTICS
DESIGN OF AIRCRAFT "SKIN" FOR MINIMUM INTERIOR FIELDS
SYSTEM TRADE-OFFS AND
DATA BASE MANAGEMENT
COMPILE DATA-BASES
(SUPERSAT)
INTRINSIC MATERIAL PROPERTIES
MATERIAL SHIELDING (S_E, S_H)
NONLINEAR DATA BASE
COMPUTER DATA BASE
ESTABLISH TRADE-OFFS USING OTHER PROGRAMS WHERE NECESSARY
PERFORM PARAMETRIC STUDIES
WEIGHT SAVED DUE TO COMPOSITES
WEIGHT LOST DUE TO INCREASED SHIELDING REQUIREMENTS
COMPILE AND TRANSMIT COMPUTER DATA BASE INTO COMPUTER
PROVIDE INPUT MATERIAL FOR PREPARATION OF GUIDELINES, SPECIFICATIONS AND STANDARDS
LOW FREQUENCY POWER TRADE-OFFS
GUIDELINES,
SPECIFICATIONS
STANDARDS
ADVANCED COMPOSITE MATERIAL AIRCRAFT WITH ELECTROMAGNETIC INTEGRITY AT MINIMUM COST

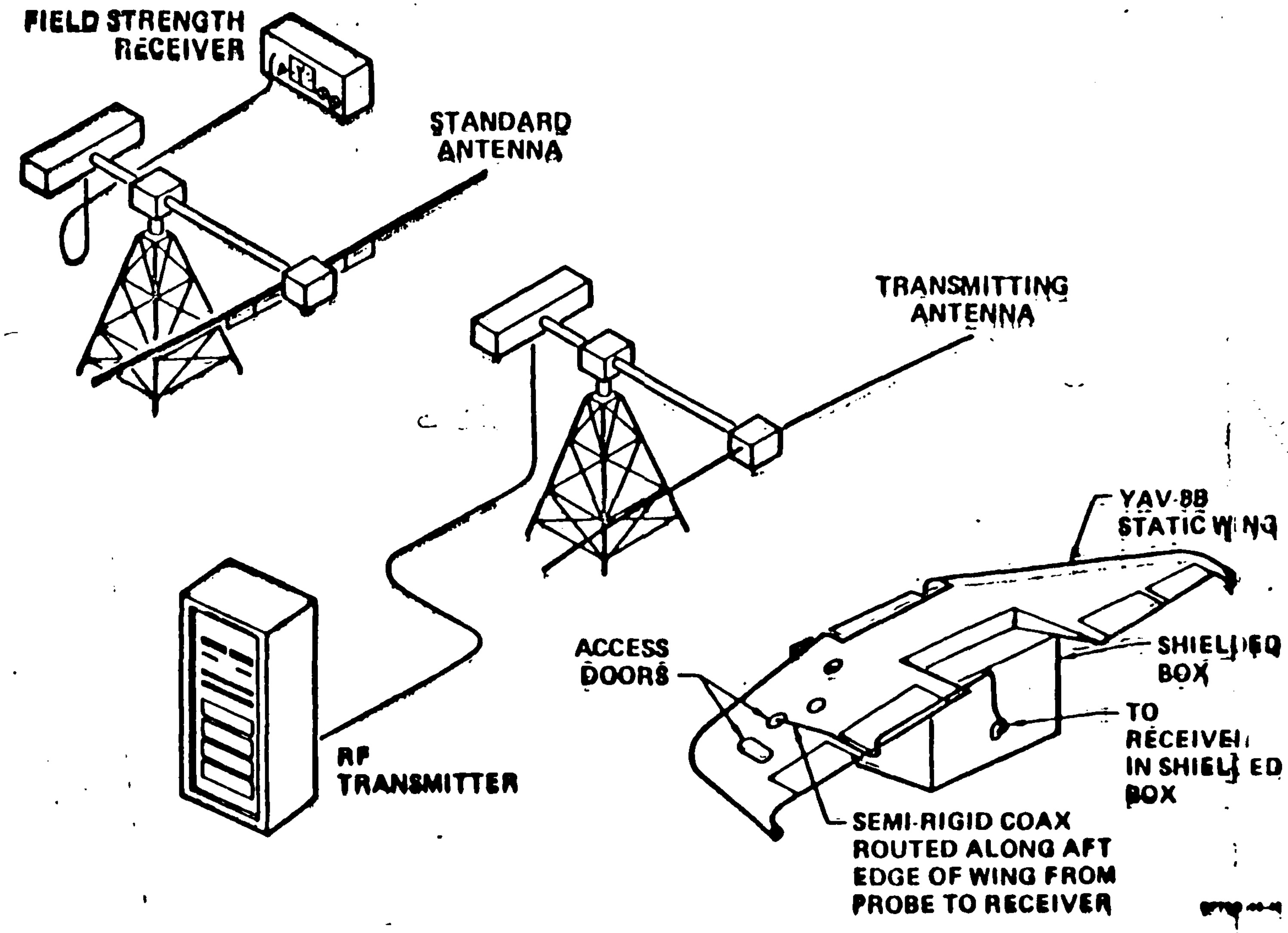
SYSTEM TRADE-OFFS AND DATA BASE MANAGEMENT (SRC)

- COMPILE DATA BASES
  - UPSET } (SUPERSAT)
  - BURNOUT
  - INTRINSIC MATERIAL PROPERTIES (ρ, μ, ϵ)
  - MATERIAL SHIELDING (S_E, S_H)
  - NONLINEAR DATA BASE
  - COMPUTER DATA BASE
- ESTABLISH TRADE-OFFS USING IEMCAP, IAP OR OTHER PROGRAMS WHERE NECESSARY
  - PERFORM PARAMETRIC STUDIES
  - WEIGHT SAVED DUE TO COMPOSITES VERSUS WEIGHT LOST DUE TO INCREASED SHIELDING REQUIREMENTS
- COMPILE AND TRANSMIT COMPUTER ALGORITHM DATA BASE INTO NAVAIR COMPUTER (NSRDC)
- PROVIDE INPUT MATERIAL FOR PREPARATION OF GUIDELINES, SPECIFICATIONS AND STANDARDS
- LOW FREQUENCY POWER TRADE-OFFS

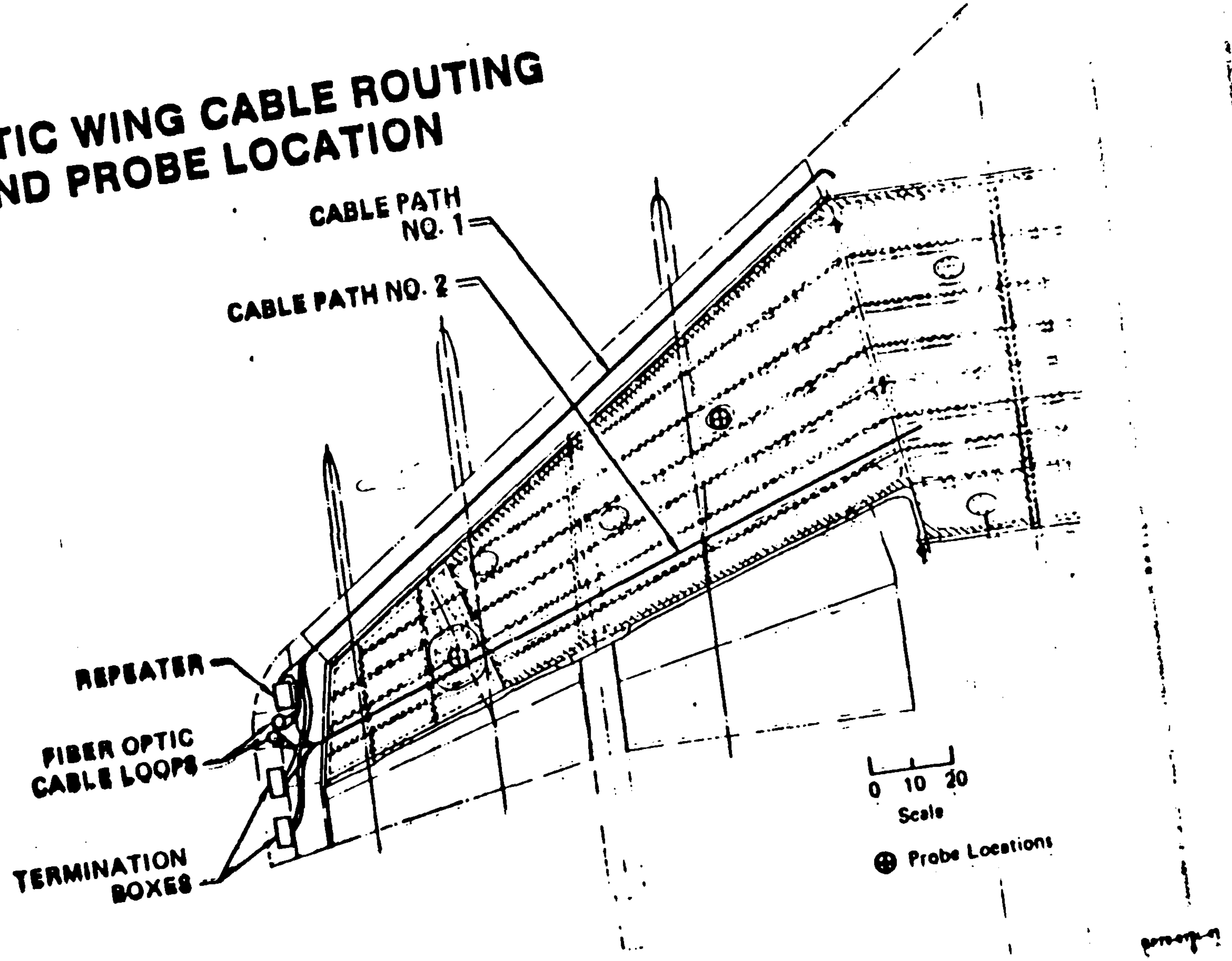
__GUIDELINES FOR ACHIEVING ELECTROMAGNETIC COMPATIBILITY USING COMPOSITE MATERIALS ON ADVANCED AIRCRAFT__

- USERS GUIDE
- STANDARDS
- SPECIFICATIONS

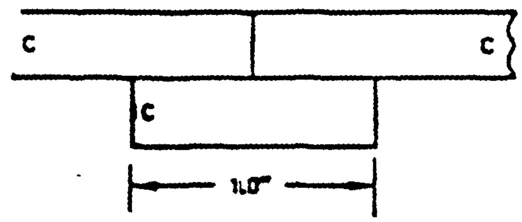
EMI TEST SET-UP



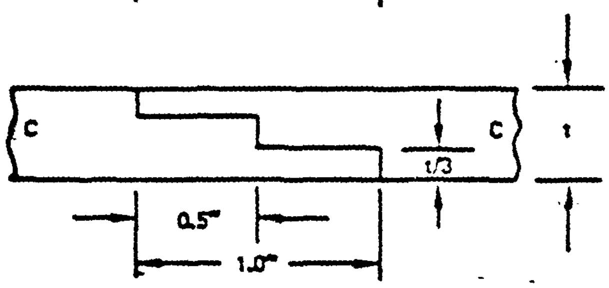
STATIC WING CABLE ROUTING AND PROBE LOCATION



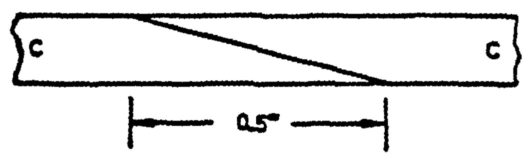
VIEW LOOKING DOWN NORMAL TO WRP



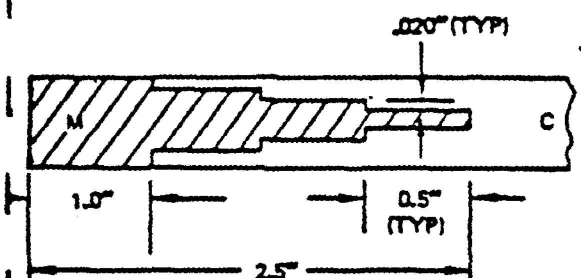
CYLINDER CENTER TOWARDS BOTTOM OF PAGE. CYLINDER WAS FABRICATED EXTRA LONG TO PROVIDE MATERIAL FOR INTER RING, WHICH WAS CUT LONGITUDINALLY AND SQUEEZED INSIDE. JOINT WAS SECONDARILY BONDED WITH EA-934 ADHESIVE.



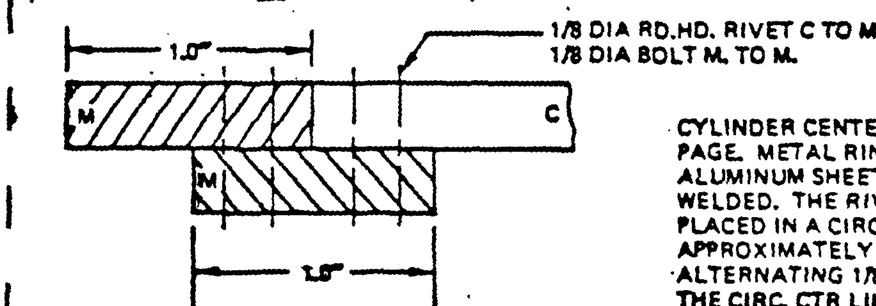
CYLINDER, FABRICATED EXTRA LONG, WAS CUT, STEPS MACHINED AND THEN JOINT WAS SECONDARILY BONDED WITH EA-934 ADHESIVE.



CYLINDER WAS FABRICATED EXTRA LONG, CUT, MACHINED AND SECONDARILY BONDED WITH EA-934 ADHESIVE.

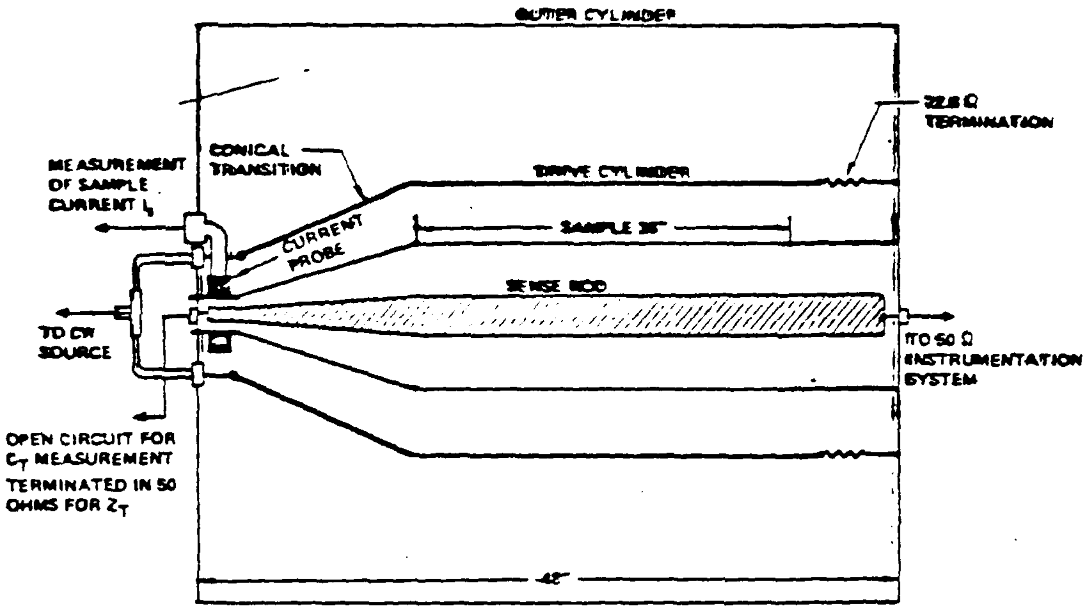


FIRST THREE STEPS (4 PLY PER STEP) WERE PRECURED (COMPACTED), EA-934 APPLIED TO SANDED COMPOSITE STEPS, AND THEN LONGITUDINALLY SLIT METAL RING MANEUVERED INTO PLACE. REMAINING COMPOSITE STEPS WERE APPLIED TO EA-934 COATED METAL RING IN PLACE. METAL RING WAS FABRICATED FROM 2024 ALUMINUM.

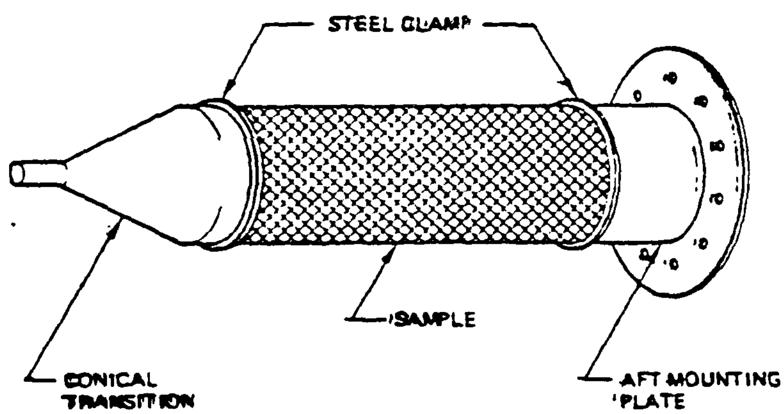


CYLINDER CENTER TOWARDS BOTTOM OF PAGE. METAL RINGS FABRICATED FROM ALUMINUM SHEET, CUT, ROLLED AND WELDED. THE RIVETS OR BOLTS WERE PLACED IN A CIRCUMFERENTIAL ROW APPROXIMATELY ONE INCH APART AND ALTERNATING 1/8 INCH TO EITHER SIDE OF THE CIRC. CTR LINE.

Figure 35 Structural Joints for Quadrax Test Specimens



(a) Schematic of quadraxial test fixture



(b) Sample cylinder clamping arrangement

Figure 5.6-1. Quadrax Test Fixture

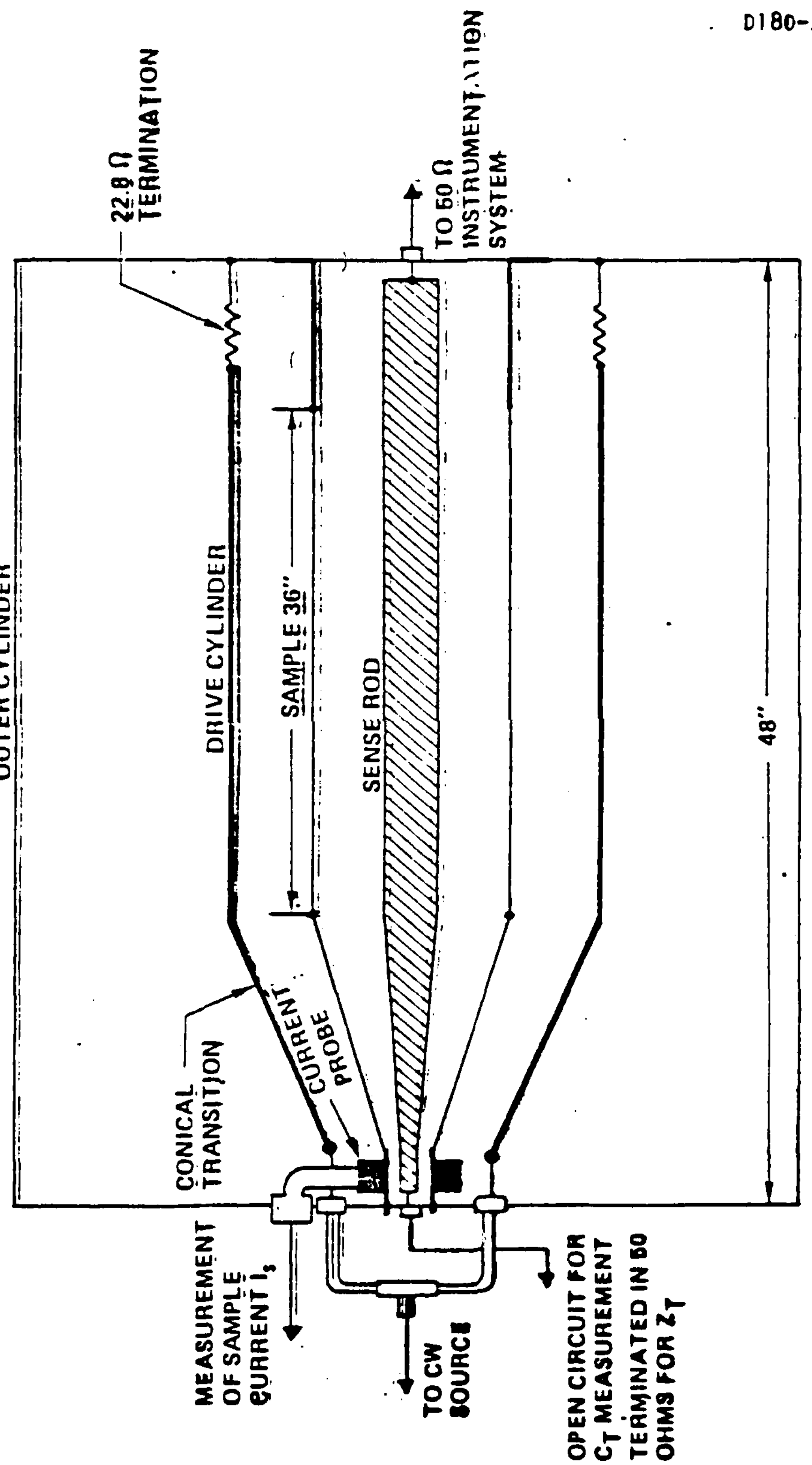
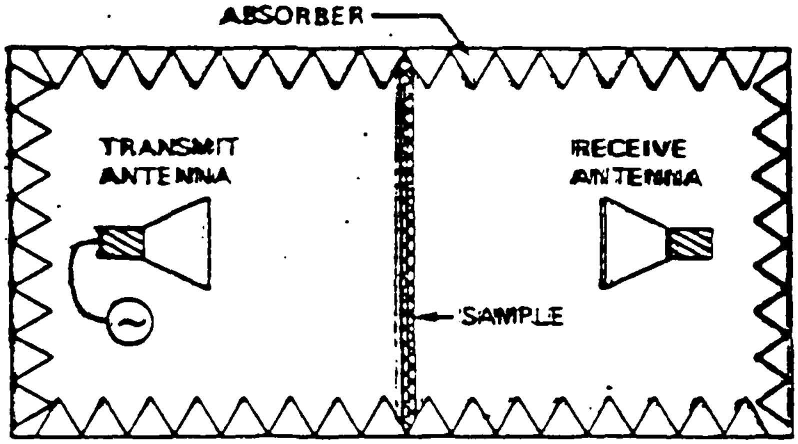
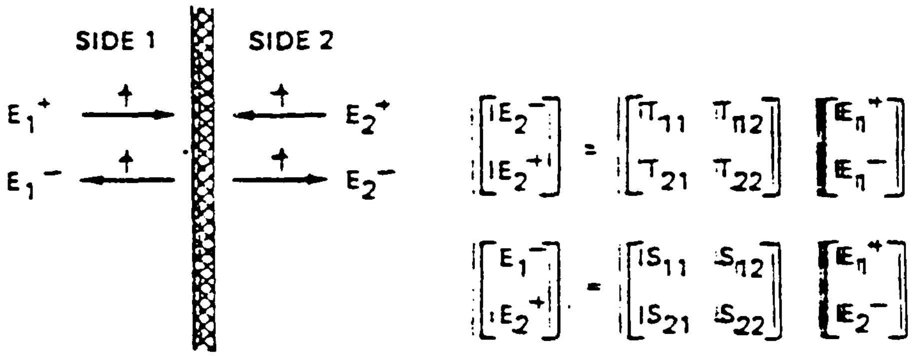


Figure 2.1-2 Schematic of Quadraxial Test Fixture



a) Anechoic chamber



b) Transmission (T) and scattering parameter (S) parameters of the material sheet

Figure 2.1-7 Transmission Parameter Measurement in an Anechoic Chamber

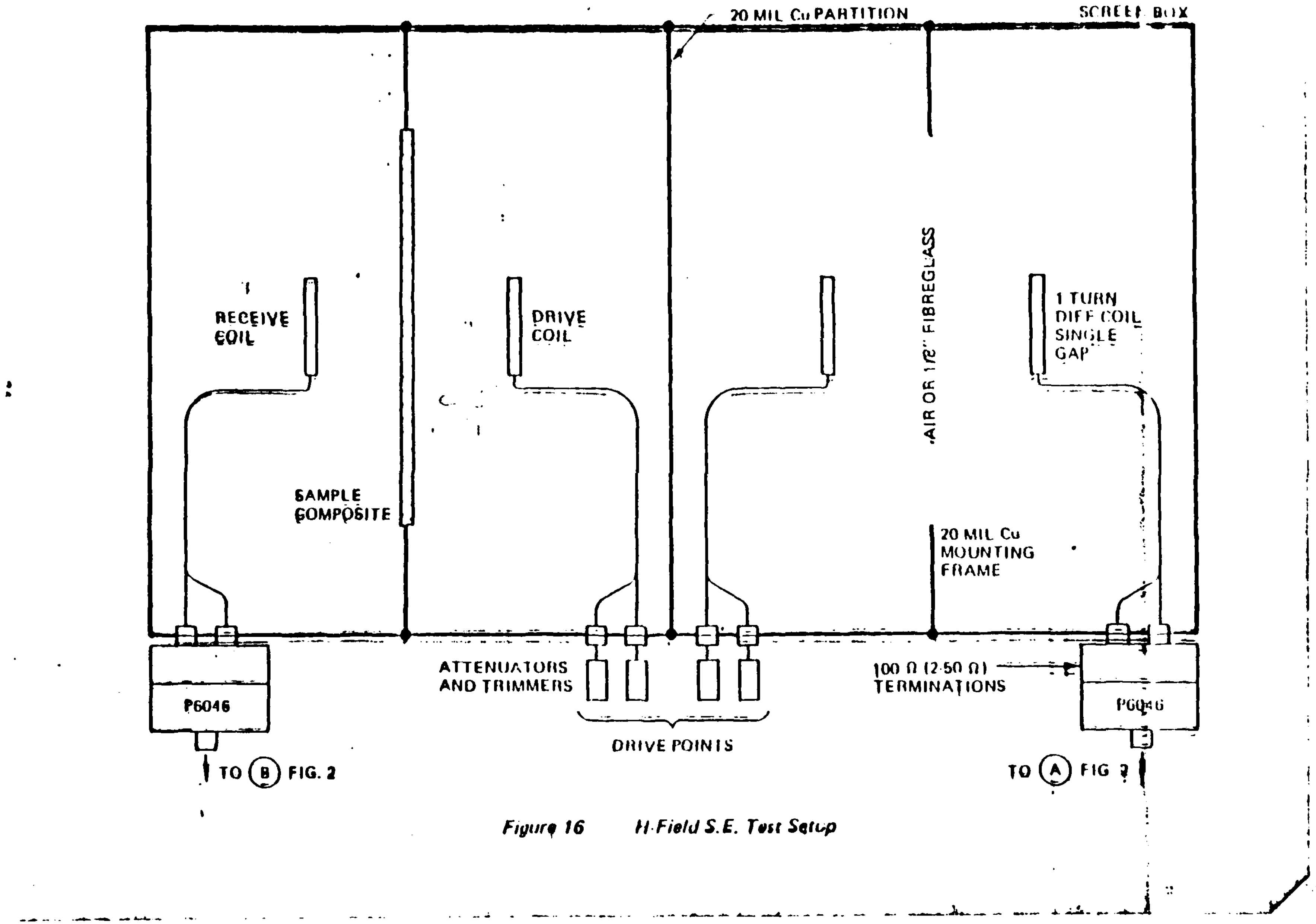
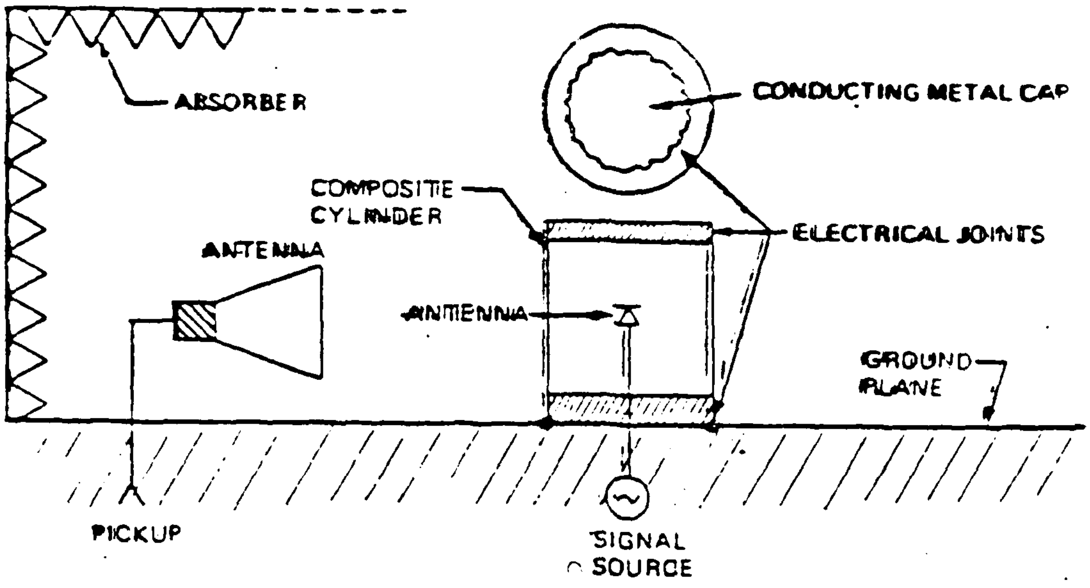
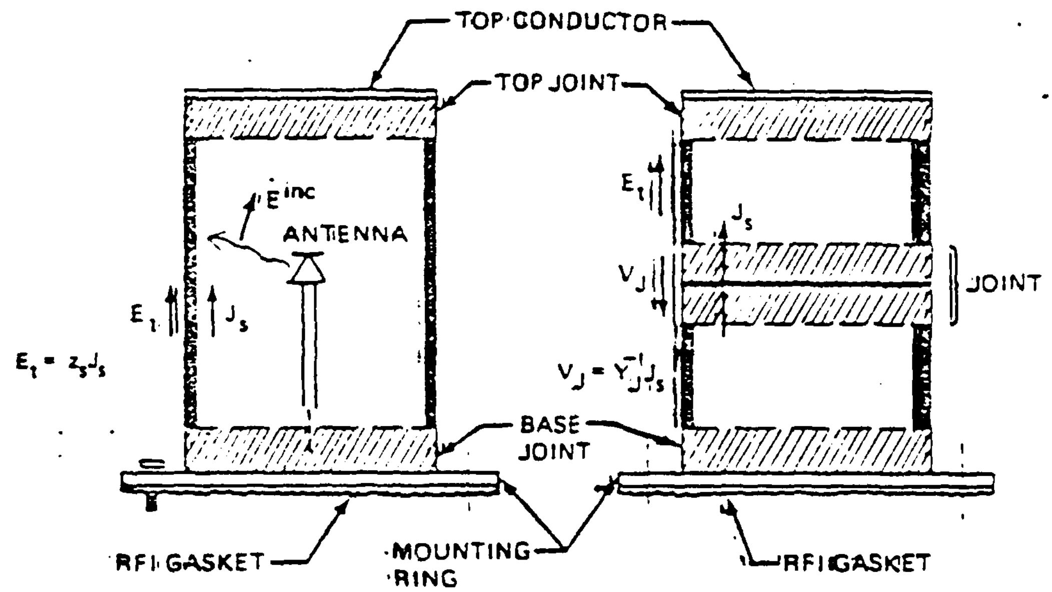


Figure 16 H-Field S.E. Test Setup

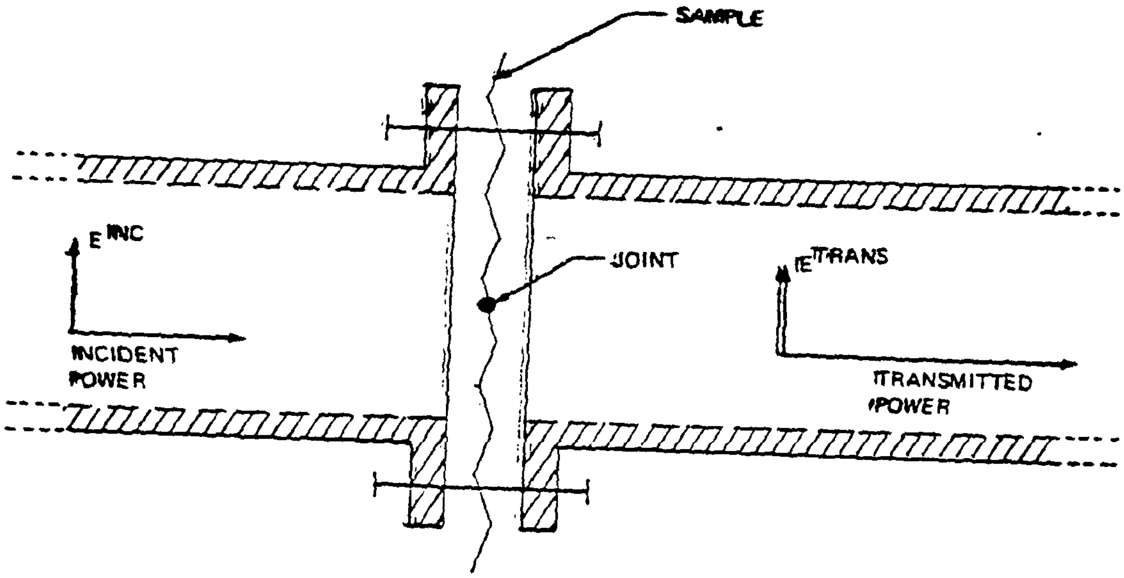


a) Test setup



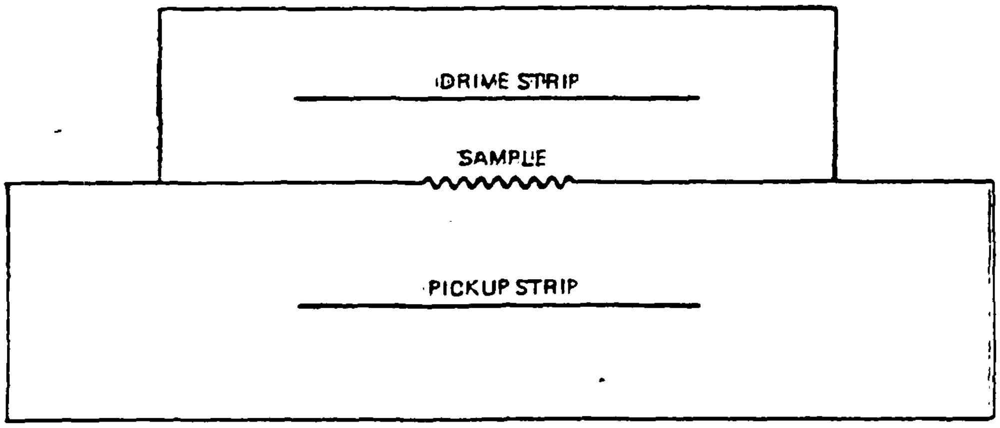
b) Cylindrical sections

Material Parameters from Shielding Measurements on Cylindrical Sections



$$\frac{E^{TRANS}}{E^{INC}} = \frac{1}{Y_i}$$

The Waveguide Transmission Concept



$$\frac{V_R}{V_G} \sim \frac{1}{Y_j}$$

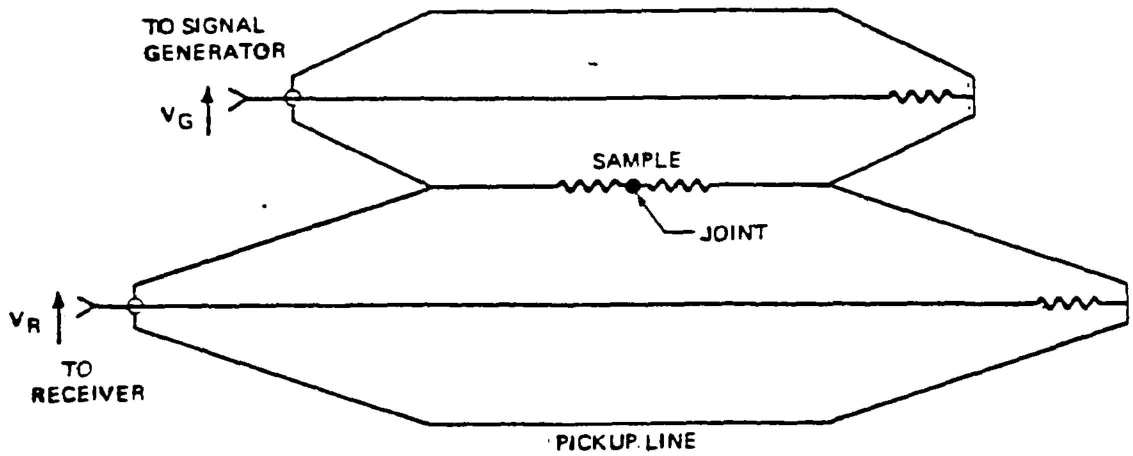
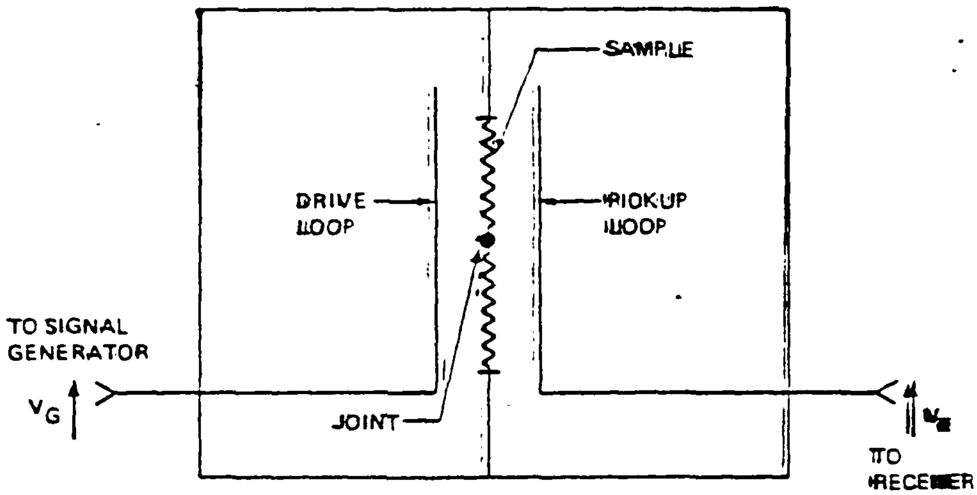
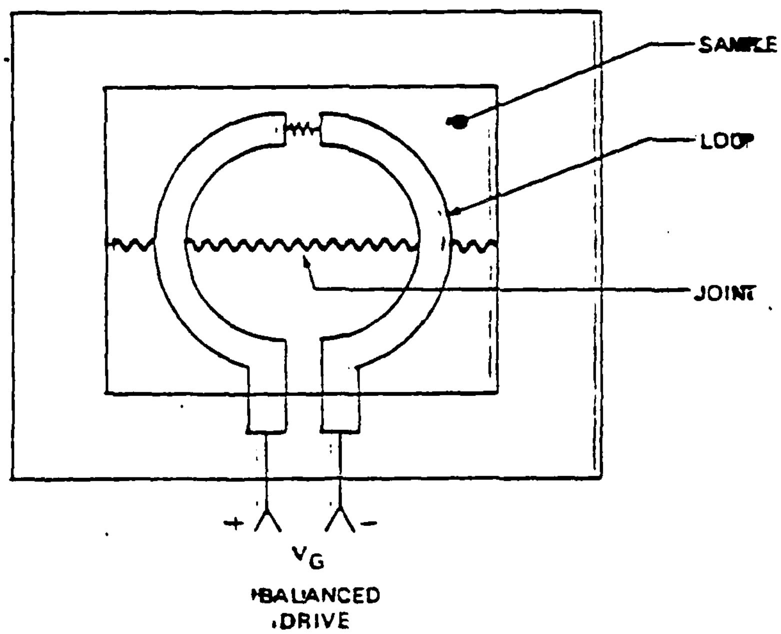


Figure 2.1-1 The Strip Line Joint Measurement Concept



$$\frac{V_R}{V_G} \sim \frac{1}{Y_j}$$



The Circular Stripline

NAVAIR SPONSORED COMPOSITE
MATERIAL EM EFFORTS

FREQUENCY	SMALL SAMPLES EFFORT	PARTICIPANT	
.01 MHz TO 50 MHz	LIGHTNING	CULHAM LABORATORY	1 OCT
.01 MHz TO 50 MHz	MATERIAL PENETRATION	NOTRE DAME	
.01 MHz TO 50 MHz	JOINT LEAKAGE	NOTRE DAME	
.10 MHz TO 50 MHz	PSTAT	NADC/NOSC/AFFDL	1 OCT
.01 MHz TO 100 MHz	EMP	NSWC/WO	
100 MHz TO 18,000 MHz	JOINT LEAKAGE	NADC/BOEING	
SELECTED IR VISIBLE, X-RAY	MATERIAL PENETRATION	NOTRE DAME	
SELECTED Y-RAYS	DEVICE INTERACTION	NSWC/WO	
DC TO DAYLIGHT AND BEYOND	SYSTEM TRADEOFFS	SRC	

NAVAIR/GOVERNMENT COOPERATIVE EFFORTS

SMALL SAMPLES

FREQUENCY	EFFORT	PARTICIPANT
.01 MHz TO 50 MHz	FLIGHT MEASUREMENT LIGHTNING DRIVING FUNCTION	AFFDL/BOEING/SRI
.01 MHz TO 1000 MHz	INTRINSIC PARAMETERS	RADC/UNIVERSITY SUPPORT
.1 MHz TO 1000 MHz	MATERIAL/JOINT PENETRATION	GEORGIA TECH./ARMY
50 MHz TO 2.5 GHz	MATERIAL/JOINT PENETRATION	LAWRENCE LIVERMORE LABORATORY/DNA
100 MHz TO 1000 MHz	MATERIAL/JOINT PENETRATION	UNIVERSITY OF COLORADO/ONR
SELECTED FREQUENCIES	MATERIAL/JOINT PENETRATION	NAVY SECTION AFWL

NAVAIR SPONSORED COMPOSITE MATERIAL EM EEFORTS

TOTAL STRUCTURE COUPLING

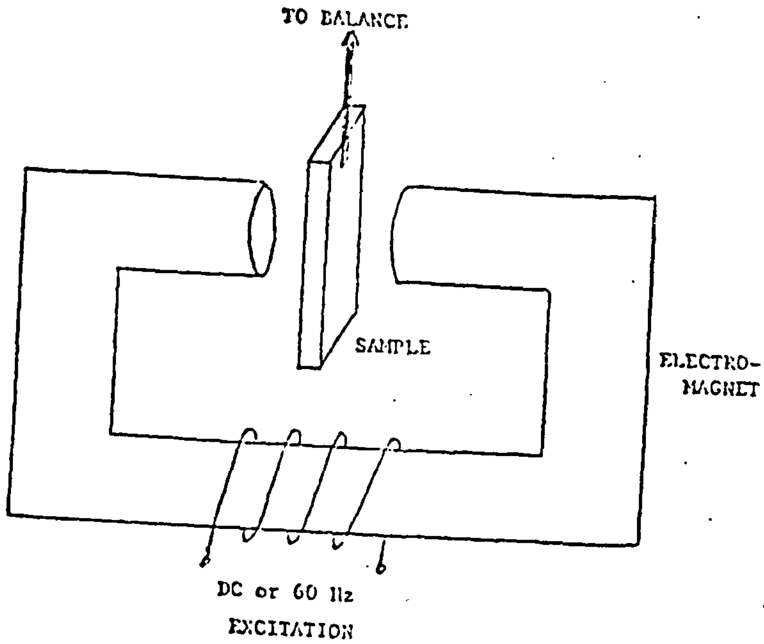
FREQUENCY	EFFORT	PARTICIPANT
.014 MHz TO 18,000 MHz	WING	NADC/NOSC/MCAIR
.014 MHz TO 18,000 MHz	FORWARD FUSELAGE	NADC/NOSC/MCAIR

Dr. Walt Gajda
Notre Dame

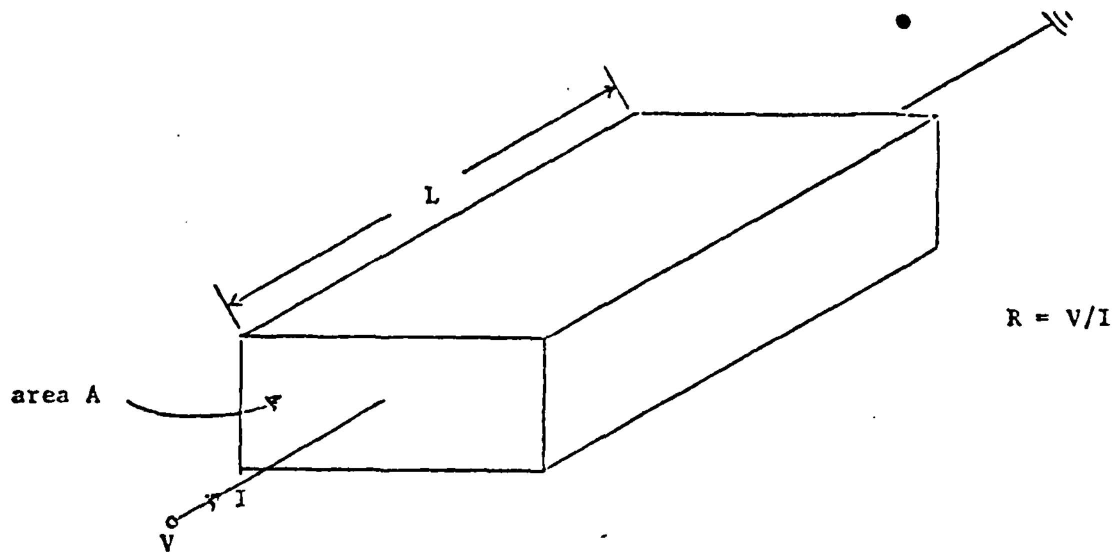
Materials Preparation, Measurements,
and Experimental Setup at Notre Dame.

ND EFFORT IN COMPOSITES

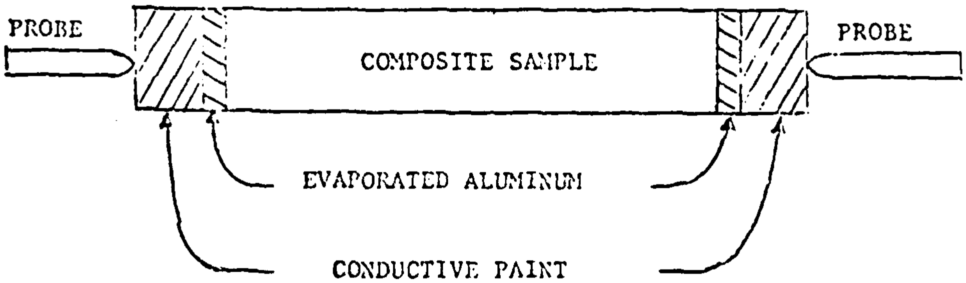
	RADC	AFOSR	NASC
975	SURVEY STATE OF ART		
.76	INTRINSIC MEASUREMENTS & MODIFICATION		
,77	INTRINSIC MEASUREMENTS	MODELS & MODIFICATION	SAMPLE FABRICATION
78	COMPLETED	MODELS & MODIFICATION	JOINT FABRICATION +



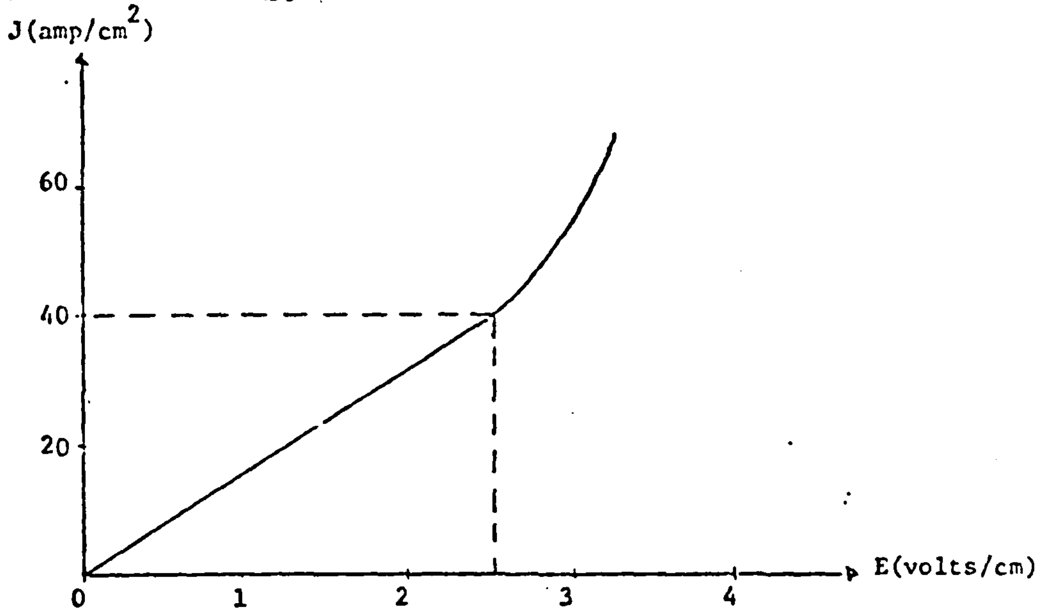
PERMEABILITY MEASUREMENT



TWO-POINT CONDUCTIVITY MEASUREMENT



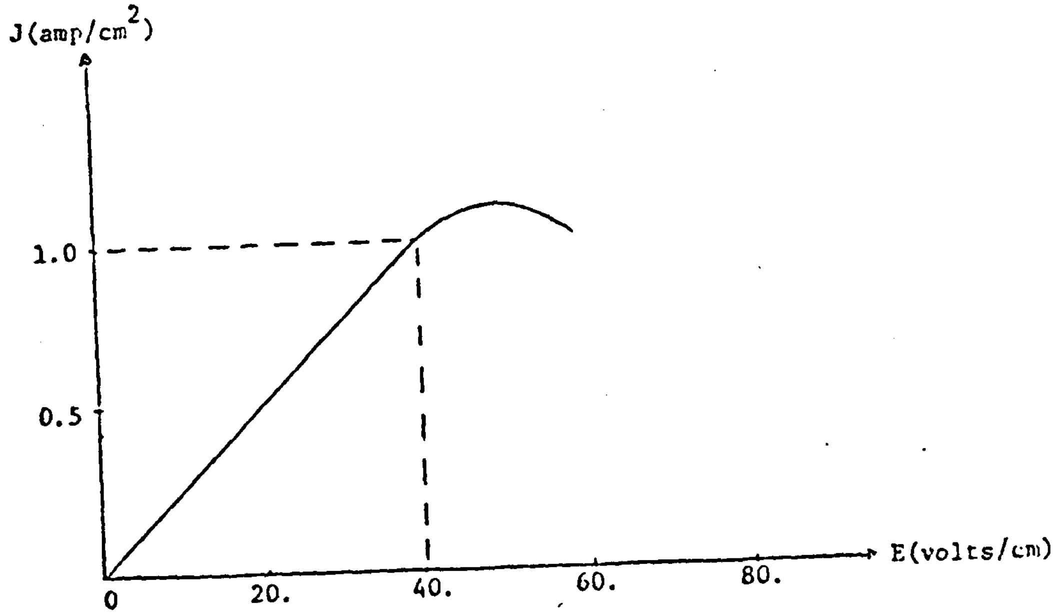
SKETCH OF CONTACT FORMATION



LONGITUDINAL CURRENT DENSITY vs. APPLIED FIELD

[illegible] 5213

No tests done yet
on 5205, 3301



TRANSVERSE CURRENT DENSITY vs. APPLIED FIELD

NARMCO 5213

No tests done yet
on 5206, 3501

Breakdown Thresholds

	E(volts/m)	J(amp/m^2)
minimum	$3.2(10^3)$	$57.6(10^6)$
average	$3.7(10^3)$	$103.2(10^6)$
maximum	$4.4(10^3)$	$125.1(10^6)$

T 300 Fibers

$$\frac{125(10^6)}{4(10^3)} = 30(10^3)\ \text{a/m}$$

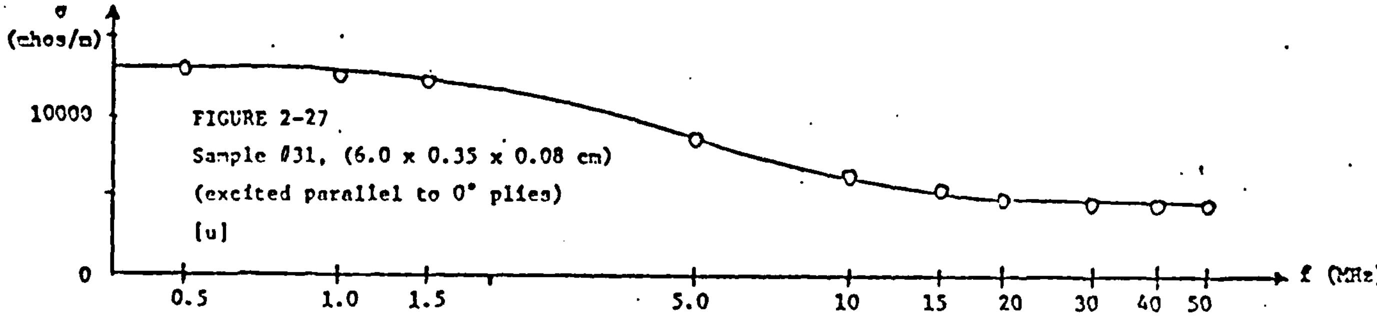


FIGURE 2-27
Sample #31, (6.0 x 0.35 x 0.08 cm)
(excited parallel to 0° plies)
[u]

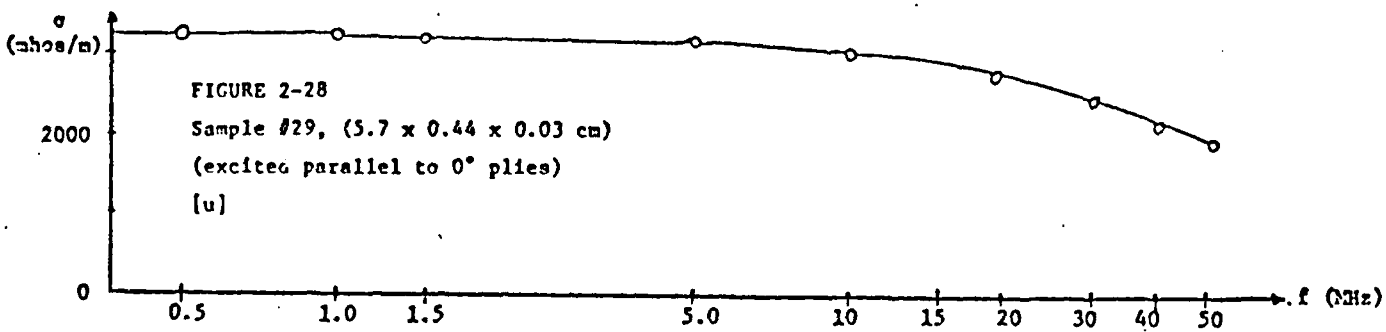


FIGURE 2-28
Sample #29, (5.7 x 0.44 x 0.03 cm)
(excited parallel to 0° plies)
[u]

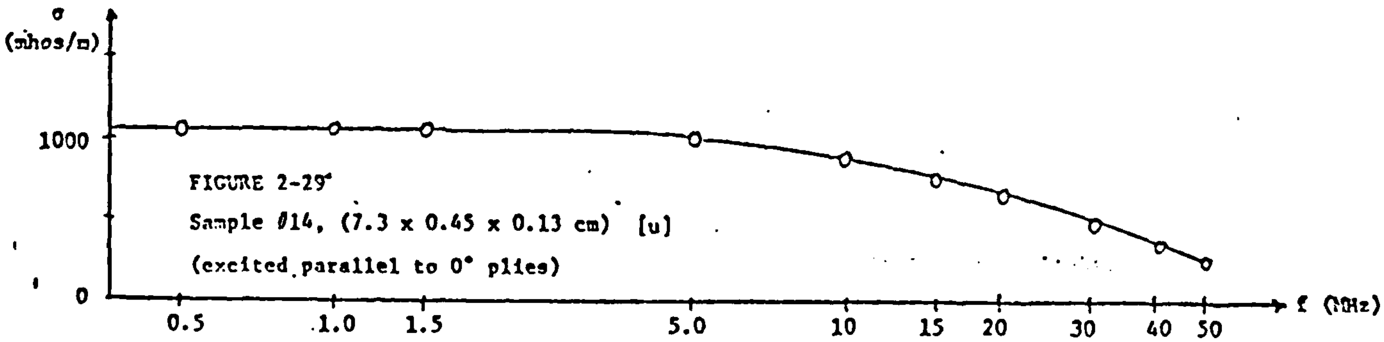
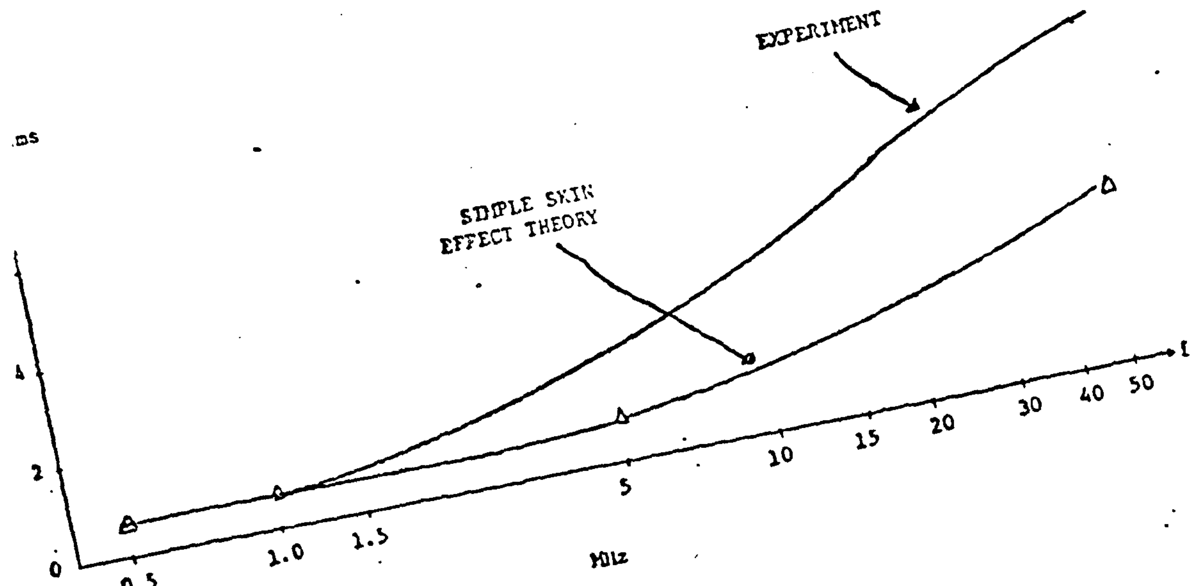


FIGURE 2-29
Sample #14, (7.3 x 0.45 x 0.13 cm) [u]
(excited parallel to 0° plies)



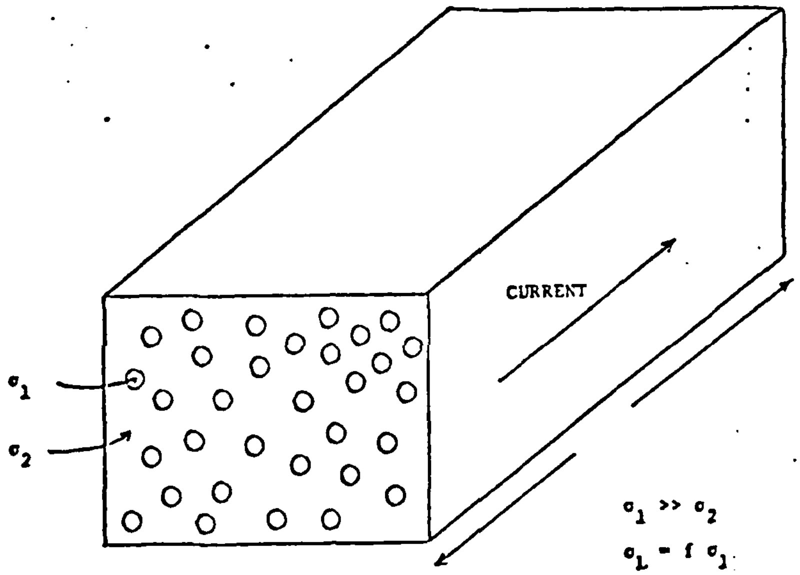
SKIN EFFECT RESULTS

	Graphite/Epoxy	Boron/Epoxy	Kevlar
Permeability μ_R	1	1	1
Permittivity ε_R	Indeterminant	5.6	3.6
DC Conductivity (mhos/m)			
longitudinal σ_L	$2(10^4)$	30	$6(10^{-9})$
transverse σ_T	100	$2(10^{-8})$	$6(10^{-9})$
Anisotropy Ratios (σ_L/σ_T)	200	$1.5(10^9)$	1
High Field Thresholds			
longitudinal			
E_{NL} (volts/m)	250	not	not
J_{NL} (amps/m^2)	$4(10^5)$	measured	measured
tranverse			
E_{NL} (volts/m)	4000	not	not
J_{NL} (amps/m^2)	$1(10^4)$	measured	measured

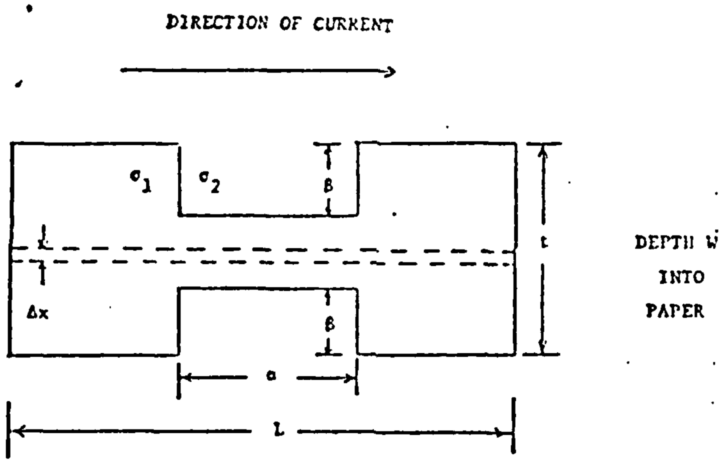
SUMMARY OF ELECTRICAL PROPERTIES OF MEASURED COMPOSITES

Ind because $\sigma \gg \omega\epsilon$
at measured freq.

$$\sigma_L = \sigma_1 f + \sigma_2(1-f)$$



MODEL FOR DETERMINATION OF σ_L



MODEL FOR CALCULATION OF σ_T

CONDUCTIVITY MODELS

NGITUDINAL $\sigma_L = f\ \sigma_f \approx 2(10^4)$

ANSVERSE $\sigma_T = 2(10^2)$

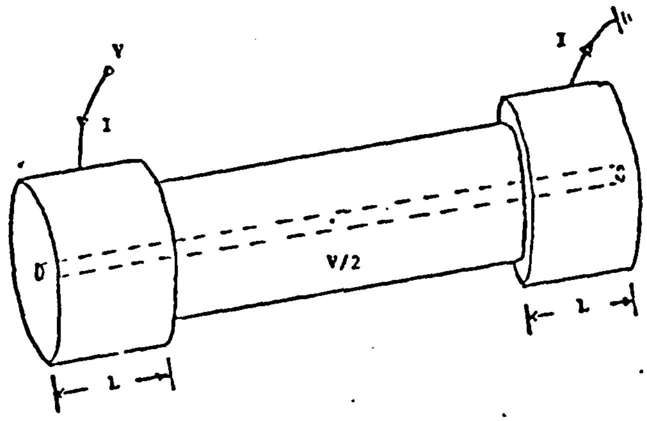
° $\sigma_{/} = 5(10^3)$

$$\sigma_e = \frac{1}{N} \sum_{i=1}^{N} \sigma_i$$

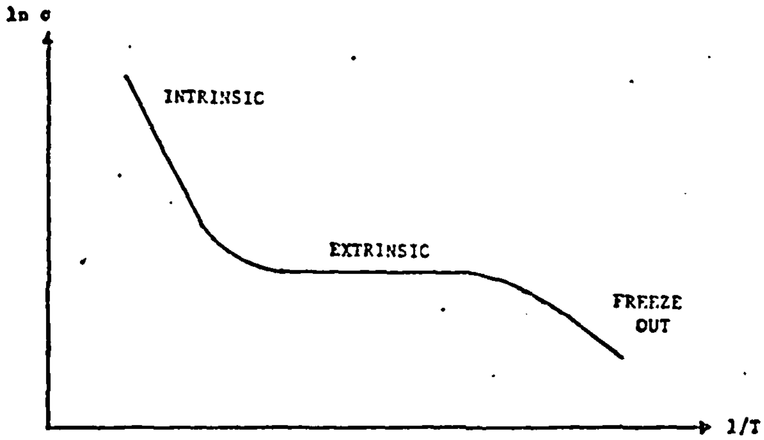
l conductivities in mhos/meter.

[illegible] $\Rightarrow$ $\sigma = 6.6(10^3)$

[illegible] $\Rightarrow$ $\sigma = 5.7(10^3)$



GEOMETRY FOR CALCULATION OF σ_B



CONDUCTIVITY-TEMPERATURE PROFILE

FOR A SIMPLE
SEMICONDUCTOR

$$\lambda = \frac{12398}{.14} \cong 6000 Å \quad 6\,\mu m$$

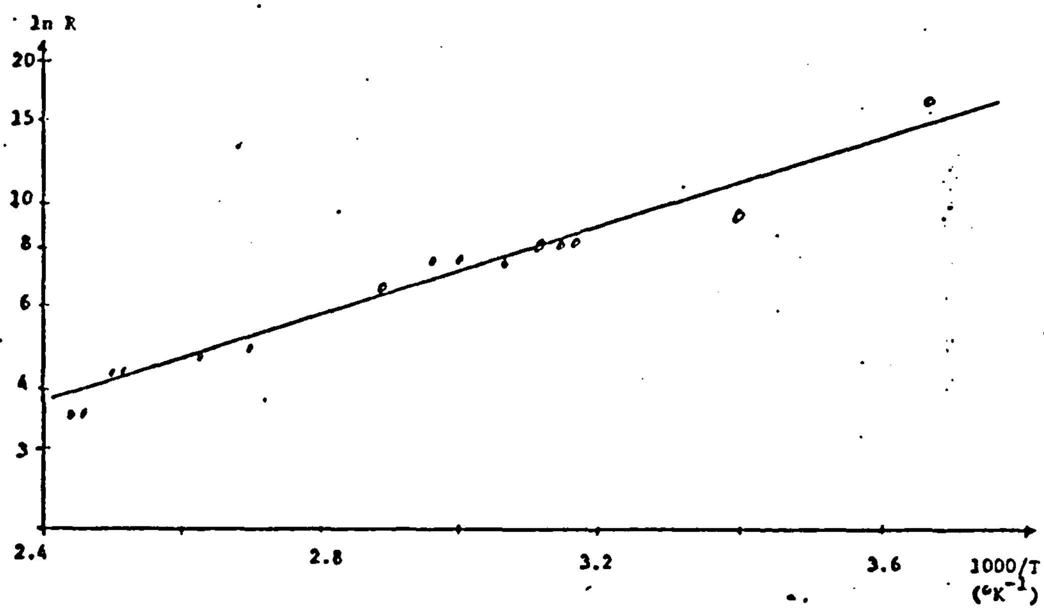
$$E = h\nu = \frac{hc}{\lambda}$$

$$\lambda = \frac{hc}{E} = \frac{(6.64(10^{-34})(3)(10^{8})}{E} = \frac{20(10^{-26})}{E(eV)(1.6(10^{-19}))}$$

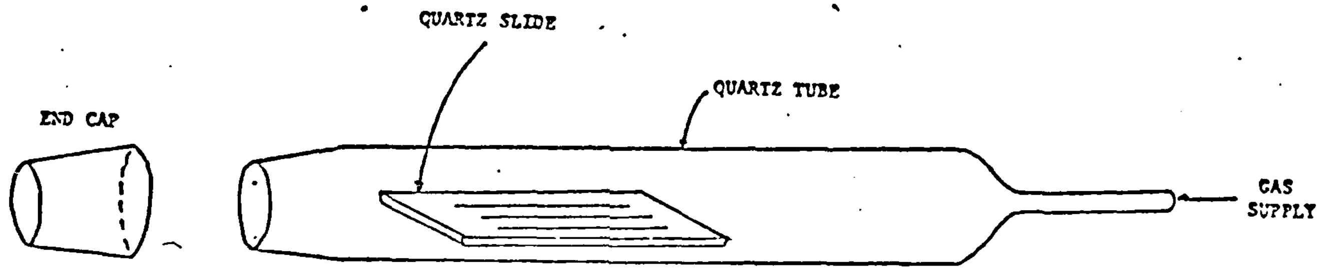
$$= \frac{12(10^{-7})}{E(eV)} \rightarrow \frac{12(10^{3})}{E} = \lambda(Å)$$

$$E_g \simeq 0.14\,eV$$

$$\lambda_g \cong 6\,\mu m$$

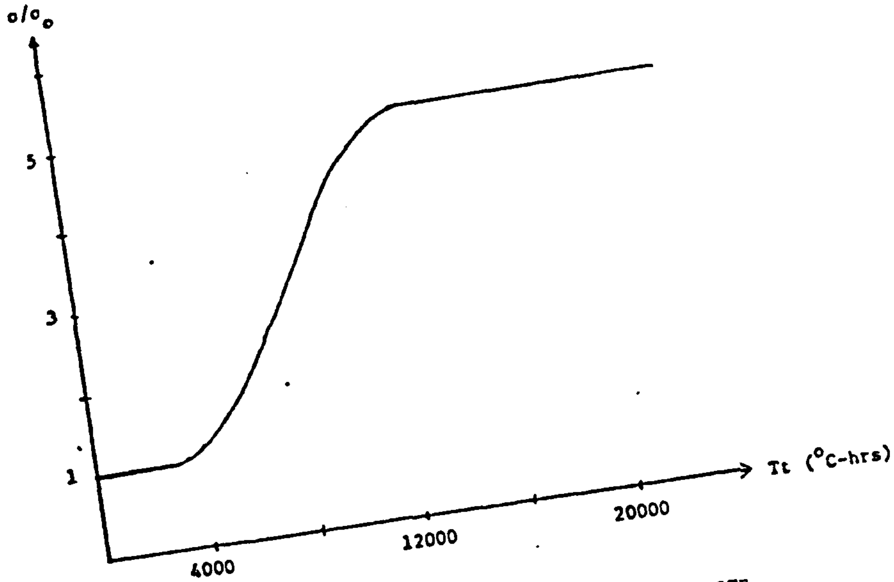


BORON FIBER ENERGY GAP



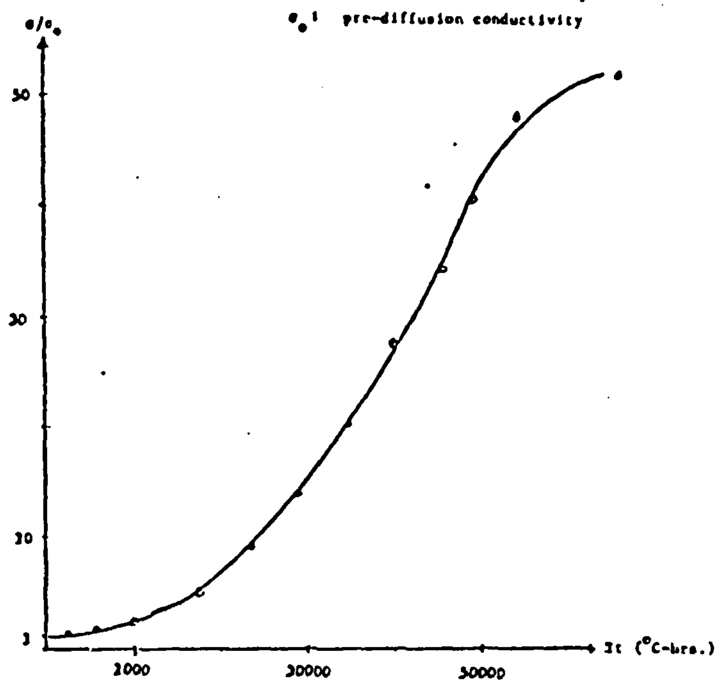
BASIC DIFFUSION FURNACE

σ_o: pre-diffusion conductivity



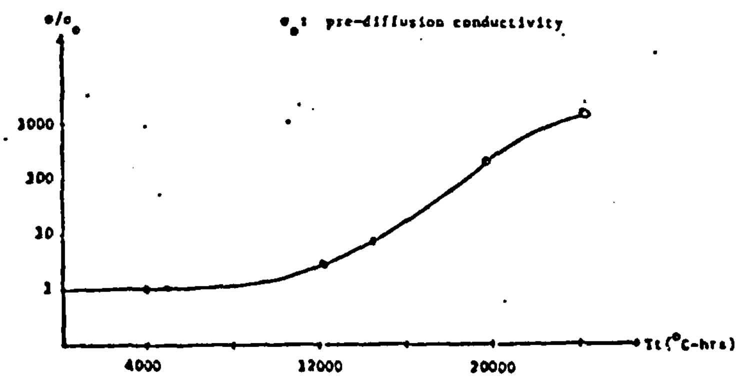
CONDUCTIVITY ENHANCEMENT IN GRAPHITE

(



CONDUCTIVITY ENHANCEMENT IN GRAPHITE
HIGH TEMPERATURE

FIGURE 16

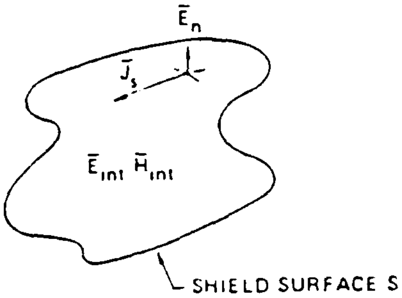


CONDUCTIVITY ENHANCEMENT IN BORON

FIGURE 17

Dr. Robert Wallenberg

Syracuse Research Corporation



Skin diffusion.

$\bar{\bar{G}}_d \sim Z_{sd}$ (open circuit diffusion transfer impedance, ohms/square)

Distributed aperture coupling (screens)

$\bar{\bar{G}}_p \sim P$ (surface electric polarizability: farads)

$\bar{\bar{G}}_m \sim M$ (surface magnetic polarizability, meters)

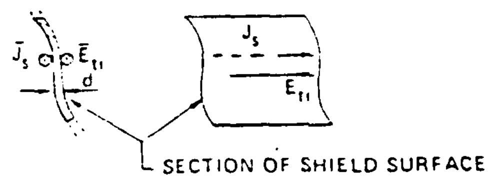
$$\begin{Bmatrix} \bar{E}_{int} \\ \bar{H}_{int} \end{Bmatrix} = \oiint_S [(\bar{\bar{G}}_d + \bar{\bar{G}}_m + \bar{\bar{G}}_j) \cdot \bar{J}_s + \bar{\bar{G}}_p \cdot \bar{E}_n] ds$$

Joint coupling

$\bar{\bar{G}}_j \sim \dfrac{1}{Y_j}$ · Y_j (joint admittance per unit of joint width or run mhos/meter)

Figure D-6.—The Relation Between Surface Response and Internal Fields

SRC



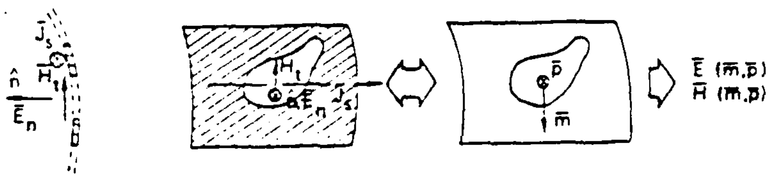
$$\bar{E}_{ti} = z_{sd}\ \bar{J}_s$$

$$z_{sd} = \frac{E_{ti}\ \text{(inner surface tangential electric field)}}{J_s\ \text{(outer surface skin current)}}$$

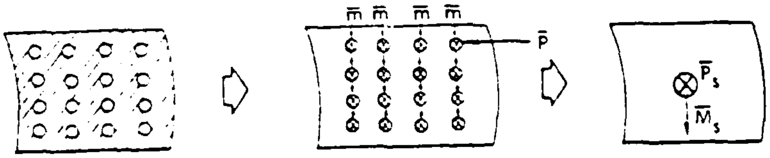
THIN FOIL SURFACE:

$$z_{sd} = \frac{\hat{\eta}}{\sinh \hat{\gamma} d} \quad ; \quad \hat{\eta} = \sqrt{\frac{j\omega\mu}{\sigma}} \quad \& \quad \hat{\gamma} = \sqrt{j\omega\mu\sigma}$$

Figure D-7.—Diffusion



Arrays of small apertures



$\bar{P}_s$ (electric dipole moment/unit area) = P $\bar{E}_n$

$\bar{M}_s$ (magnetic dipole moment/unit area) = M $\hat{n} \times \bar{J}_s$

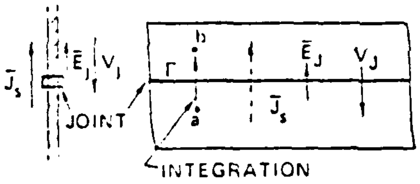
P (electric surface polarizability) = $n\alpha_E$

M (magnetic surface polarizability) = $n\alpha_H$

Example For circular apertures of radius r_o

$$\alpha_E = \frac{4}{3} r_o^3 \qquad \alpha_H = \frac{8}{3} r_o^3$$

Figure D-8.—Quasi-Static Aperture Coupling



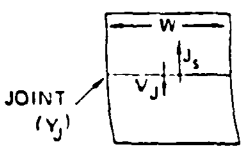
Joint voltage

$$V_J = \int_a^b \bar{E}_J \cdot \overline{dl} = \frac{J_s}{Y_J}$$

Y_J (joint coupling admittance per unit joint width)

$$Y_J = \frac{J_s}{V_J} \quad \text{(mhos/meter)}$$

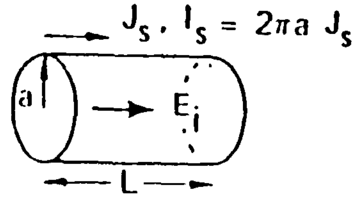
Example. Perfect sheets with joint



1. Total joint admittance
$$Y_{tot} = Y_J W$$
2. Total joint current:
$$I_{tot} = J_s W$$
3. Joint voltage:
$$V_J = \frac{I_{tot}}{Y_{tot}} = \frac{J_s W}{Y_J W} = \frac{J_s}{Y_J}$$

Figure D-9.—Joint Coupling

Surface transfer impedance
(diffusion and mag. aperture coupling)

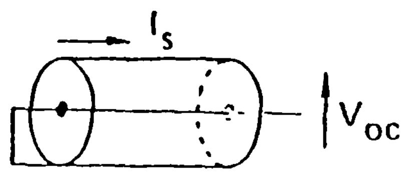


$E_i = J_s\ z_s = I_s\ Z_T$

WHERE

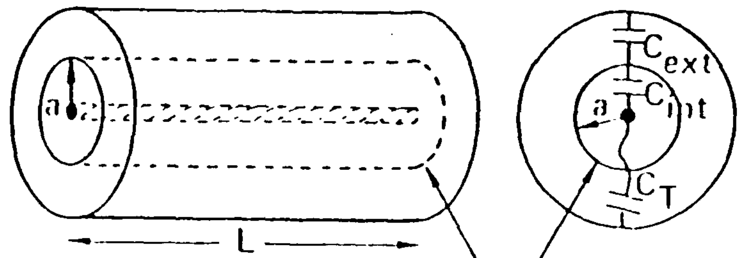
$z_s = z_{sd} + \frac{j\omega\mu_0 M}{2}$ (ohms/square)

$Z_T = \frac{z_s}{2\pi a}$ (ohms/meter)



$V_{oc} = Z_T L\ \ I_s$

Surface transfer admittance
(electric aperture coupling)



Transfer capacitance:

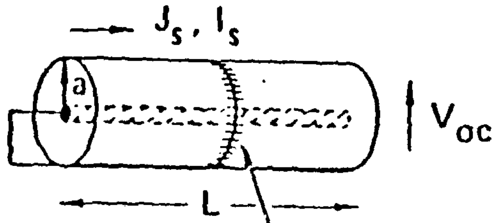
$C_T = \frac{P\ C_{int}\ \ C_{ext}}{4\pi a \epsilon^2}$ (farads/meter)

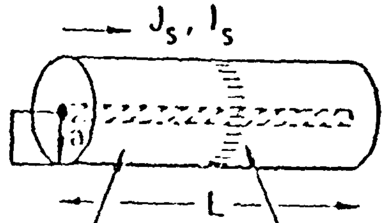
Transfer admittance per unit length:

$Y_T = j\omega C_T$

Figure D-10.—Surface Transfer Impedance and Admittance

SRC





$$V_{oc} = V_J = \frac{J_s}{Y_J} = \frac{I_s}{2\pi a Y_J}$$

$$V_{oc} = I_s \left(Z_T L + \frac{1}{Y_J 2\pi a} \right)$$

$$Y_J = \frac{I_s}{2\pi a V_J}$$

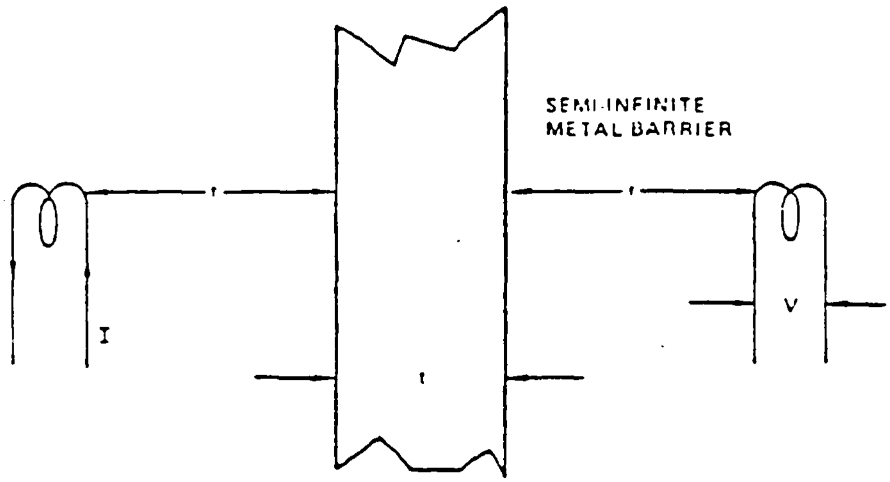
$$Y_J^{-1} = 2\pi a \left(\frac{V_{oc}}{I_s} - Z_T L \right)$$

$$Z_T,\ Y_T,\ Y_J \longleftrightarrow z_{sd},\ P,\ M,\ Y_J$$

Figure D-11.—Joint Admittance

91

6



MSE = MAGNETIC SHIELDING EFFECTIVENESS = $20 \log_{10} \frac{V_1}{V_2}$ DECIBELS.

WHERE V_1 IS MEASURED WITH BARRIER ABSENT AND V_2 WITH BARRIER PRESENT, I BEING KEPT CONSTANT.

$$MSE = A + R_1 + R_2 \tag{1}$$

WHERE

$$A = \text{ABSORPTION LOSS (dB)} = 3.3 \times 10^{-3}\, t \sqrt{f\sigma\mu} \tag{2}$$

R_1 = REFLECTION LOSS (dB) =

$$20 \log_{10} \left[\frac{0.46}{r} \sqrt{\frac{\mu}{\sigma}} + 0.14 r \sqrt{\frac{\sigma f}{\mu}} + 0.35 \right] \tag{3}$$

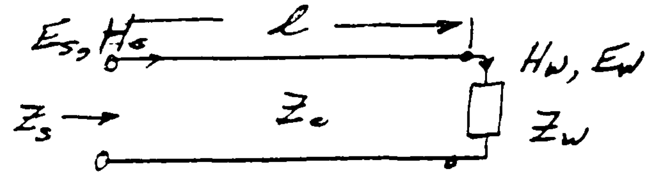
R_2 = RE-REFLECTION LOSS (dB) =

$$10 \log_{10} \left[1 - (2 \times 10^{-0.1A})(\cos 0.23A) + 10^{-0.2A} \right] \tag{4}$$

AND WHERE

- t = METAL THICKNESS (MILS)
- σ = CONDUCTIVITY RELATIVE TO COPPER
- μ = PERMEABILITY RELATIVE TO VACUUM
- r = SOURCE TO BARRIER DISTANCE (IN.)
- f = FREQUENCY (Hz)

Figure D-12.—Magnetic Shielding Effectiveness Equations for Flat Plate Test



$$Z_c = \sqrt{\frac{j\omega\mu_0}{\sigma + j\omega\varepsilon}} \qquad \gamma = \sqrt{j\omega\mu_0(\sigma + j\omega\varepsilon)}$$

FOR COMPOSITE MATERIAL: $\sigma \gg \omega\varepsilon$

$$Z_c = \sqrt{\frac{j\omega\mu_0}{\sigma}} \qquad \gamma = \sqrt{j\omega\mu_0\sigma}$$

IN FAR FIELD $Z_w = \sqrt{\frac{\mu_0}{\varepsilon_0}}$ (Plane Wave Conditions)

MAGNETIC SHIELDING: $20\log_{10}\left(\frac{H_w}{H_s}\right)$

$$\frac{H_w}{H_s} = \frac{1}{\cosh\gamma\ell + \frac{Z_w}{Z_c}\sinh\gamma\ell} \approx \frac{1}{1 + \sqrt{\frac{\sigma}{j\omega\varepsilon}}\sin\gamma\ell}$$

ELECTRIC SHIELDING: $20\log_{10}\left(\frac{E_w}{E_s}\right)$

$$\frac{E_w}{E_s} = \frac{1}{\cos\gamma\ell + \frac{Z_c}{Z_w}\sinh\gamma\ell} \approx \frac{1}{1 + \sqrt{\frac{j\omega\varepsilon}{\sigma}}\sinh\gamma\ell}$$

TRANSFER IMPEDANCE:

$$Z_{sd} = \frac{E_w}{J_s} = \frac{Z_w}{\cosh\gamma\ell + \frac{Z_w}{Z_c}\sinh\gamma\ell} \approx \frac{Z_c}{\sinh\gamma\ell}$$

USE OF JOINT ADMITTANCES AND TRANSFER IMPEDANCES

$$V_{pk} = \frac{2E_{pk}}{Y_J \eta_o} = \frac{2 \times 50 \times 10^3}{15 \times 377} = 17.7 \text{ volts}$$

The full peak is just the direct plus reflected signals, or

$$V_{pk} = \frac{2E_{pk}}{Y_J \eta_o} \times \frac{2 Z_o}{Z_o + Z_L} = \frac{2 \times 50 \times 10^3}{15 \times 377} \times \frac{2 \times 100}{100 + 30} = 27.2 \text{ volts}$$

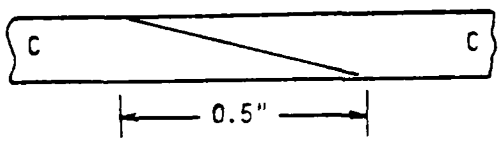
$2 Z_o/(Z_o + Z_L)$ = factor for constructive interference of direct and reflected waves

$$V_{pk} = \frac{1}{\sigma d} E_{pk} \frac{2L_{eff}}{\eta_o} \frac{2 Z_o}{Z_o + Z_L}$$

$$= \frac{1}{10^4 \times .0025} \times 50 \times 10^3 \times \frac{2 \times 5.17}{377} \times \frac{2 \times 100}{100 + 30} = 84.4 \text{ volts}$$

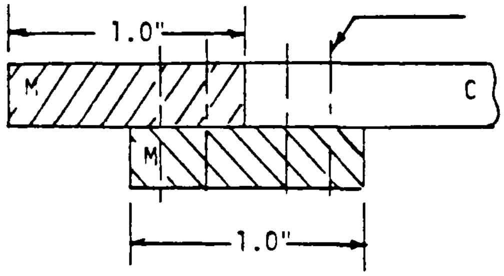
(

1



CYLINDER WAS FABRICATED EXTRA LONG, CUT, MACHINED AND SECONDARILY BONDED WITH EA-934 ADHESIVE.

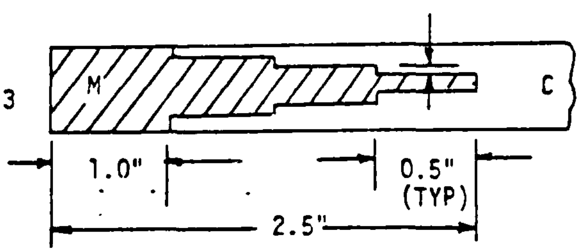
2



1/8 DIA RD.HD. RIVET C TO M
1/8 DIA BOLT M. TO M.

CYLINDER CENTER TOWARDS BOTTOM OF PAGE. METAL RINGS FABRICATED FROM ALUMINUM SHEET, CUT, ROLLED AND WELDED. THE RIVETS OR BOLTS WERE PLACED IN A CIRCUMFERENTIAL ROW APPROXIMATELY ONE INCH APART AND ALTERNATING 1/8 INCH TO EITHER SIDE OF THE CIRC. CTR LINE.

3



FIRST THREE STEPS (4 PLY PER STEP) WERE PRECURED (COMPACTED), EA-934 APPLIED TO SANDED COMPOSITE STEPS, AND THEN LONGITUDINALLY SLIT METAL RING MANEUVERED INTO PLACE. REMAINING COMPOSITE STEPS WERE APPLIED TO EA-934 COATED METAL RING IN PLACE. METAL RING WAS FABRICATED FROM 2024 ALUMINUM.

Figure 84.—Structural Joints

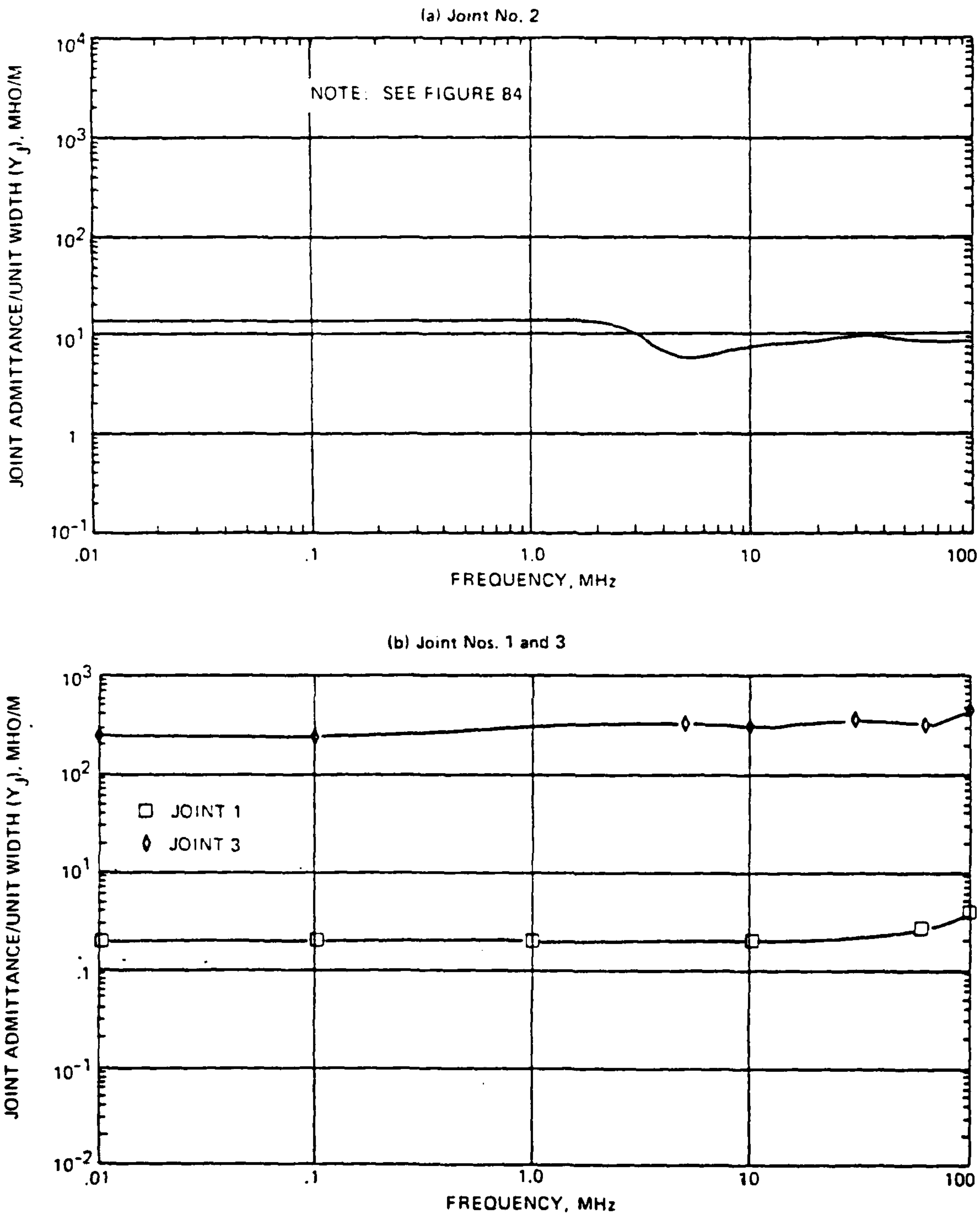


Figure 83.—Measured Joint Admittance

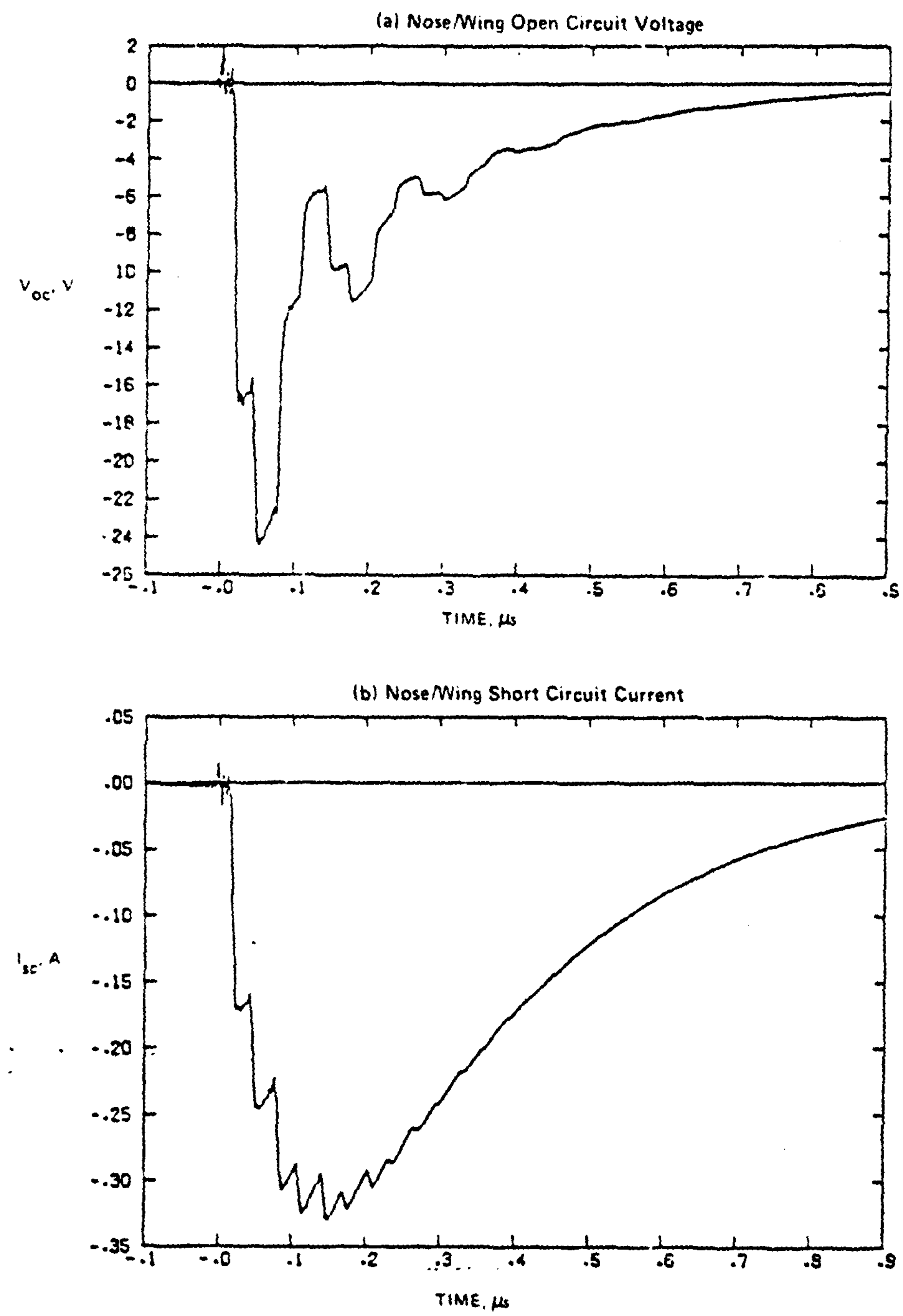


Figure 93.—V_{oc}, I_{sc} on Nose/Wing Tip Wire, NEMP, E to Fuselage, Wing Joint

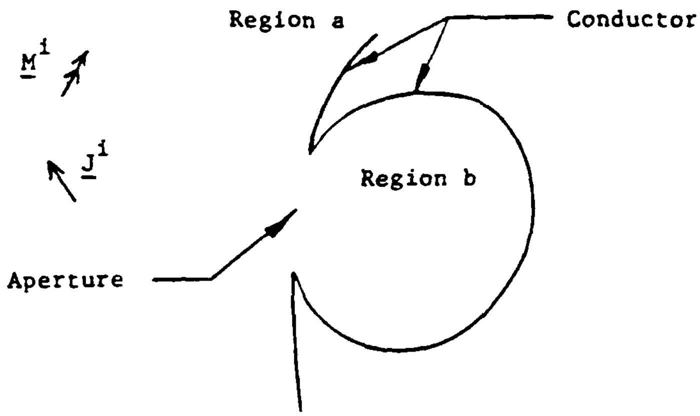
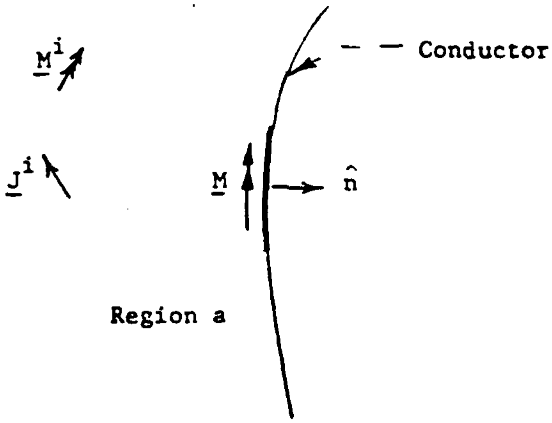
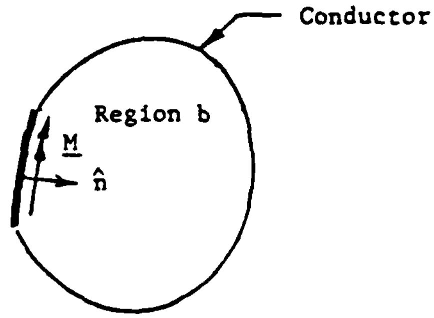


Figure 2.5.1 The General Problem of Two Regions Coupled by an Aperture



a) Equivalence for Region a



b) Equivalence for Region b

Figure 2.5.2 The Original Problem Divided into Two Equivalent Problems

SRC

GENERAL FORMULATION FOR APERTURES

$$\underline{M} = \hat{n} \times \underline{E},$$

$$H_t^a = H_t^i + H_t^a(\underline{M}) \qquad H_t^b = H_t^b(-\underline{M}) = -H_t^b(\underline{M})$$

$$H_t^a(\underline{M}) + H_t^b(\underline{M}) = -H_t^i$$

$$\underline{M} = \sum_n V_n \underline{M}_n \qquad \sum_n V_n H_t^a(\underline{M}_n) + \sum_n V_n H_t^b(\underline{M}_n) = -H_t^i$$

$$<\underline{A}, \underline{B}> = \iint_{\text{apert.}} \underline{A} \cdot \underline{B} \, ds$$

$$\sum_n V_n < W_m, H_t^a(\underline{M}_n)> + \sum_n V_n < W_m, H_t^b(\underline{M}_n)> = -< W_m, H_t^i>$$

$$[Y^a] = [<-W_m, H_t^a(\underline{M}_n)>]_{NxN}, \qquad [Y^b] = [<-W_m, H_t^b(\underline{M}_n)>]_{NxN},$$

$$\vec{I}^i = [< W_m, H_t^i>]_{Nx1} \qquad \vec{V} = [V_n]_{Nx1}$$

$$[Y^a + Y^b]\vec{V} = \vec{I}^i \qquad \vec{V} = [Y^a + Y^b]^{-1}\vec{I}^i$$

GENERAL FORMULATION FOR APERTURES

$$\underline{M} = \hat{n} \times \underline{E},$$

$$H_t^a = H_t^i + H_t^a(\underline{M}) \qquad H_t^b = H_t^b(-\underline{M}) = -H_t^b(\underline{M})$$

$$H_t^a(\underline{M}) + H_t^b(\underline{M}) = -H_t^i$$

$$\underline{M} = \sum_n V_n \underline{M}_n \qquad \sum_n V_n H_t^a(\underline{M}_n) + \sum_n V_n H_t^b(\underline{M}_n) = -H_t^i$$

$$\langle \underline{A}, \underline{B} \rangle = \iint_{\text{apert.}} \underline{A} \cdot \underline{B} \, ds$$

$$\sum_n V_n \langle W_m, H_t^a(\underline{M}_n) \rangle + \sum_n V_n \langle W_m, H_t^b(\underline{M}_n) \rangle = -\langle W_m, H_t^i \rangle$$

$$[Y^a] = [\langle -W_m, H_t^a(\underline{M}_n) \rangle]_{N\times N}, \qquad [Y^b] = [\langle -W_m, H_t^b(\underline{M}_n) \rangle]_{N\times N},$$

$$\vec{I}^i = [\langle W_m, H_t^i \rangle]_{N\times 1} \qquad \vec{V} = [V_n]_{N\times 1}$$

$$[Y^a + Y^b]\vec{V} = \vec{I}^i \qquad \vec{V} = [Y^a + Y^b]^{-1}\vec{I}^i$$

SRC

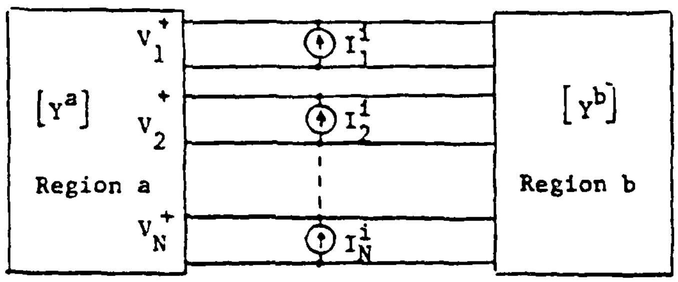


Figure 2.5.3 The Generalized Network Equivalent for an Aperture Problem

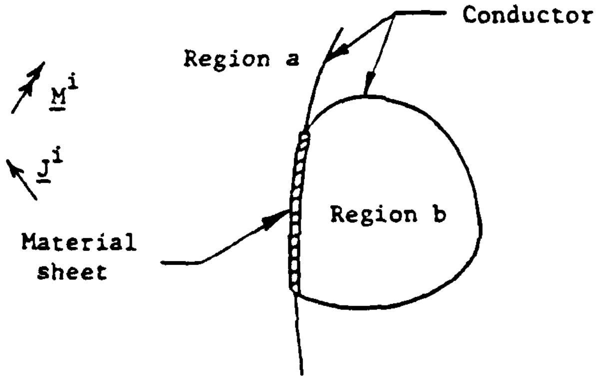


Figure 2.5.4 An Aperture Covered by a Material Sheet

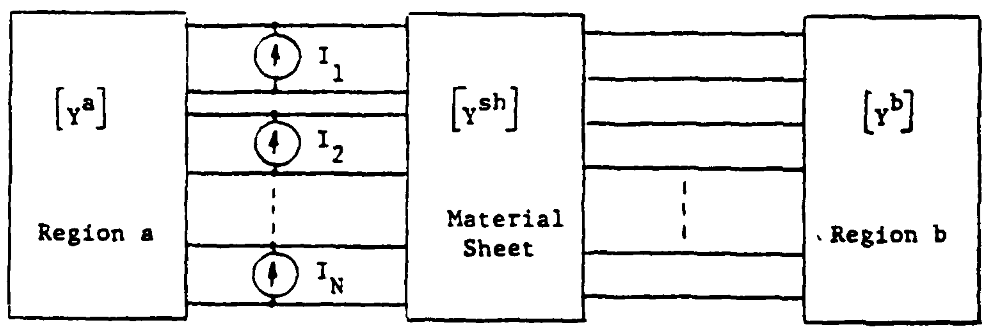
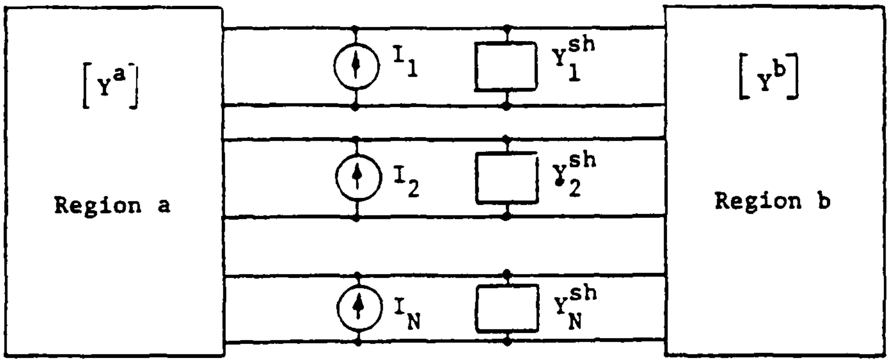
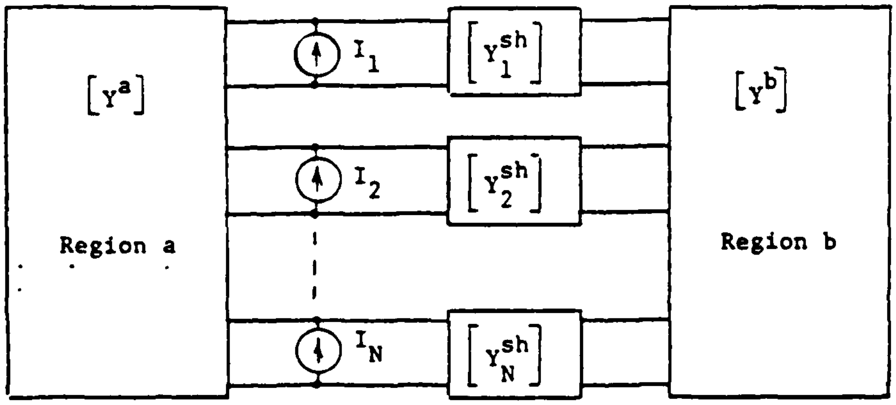


Figure 2.5.5 Generalized Network Equivalent for the Problem of Figure 2.5.4

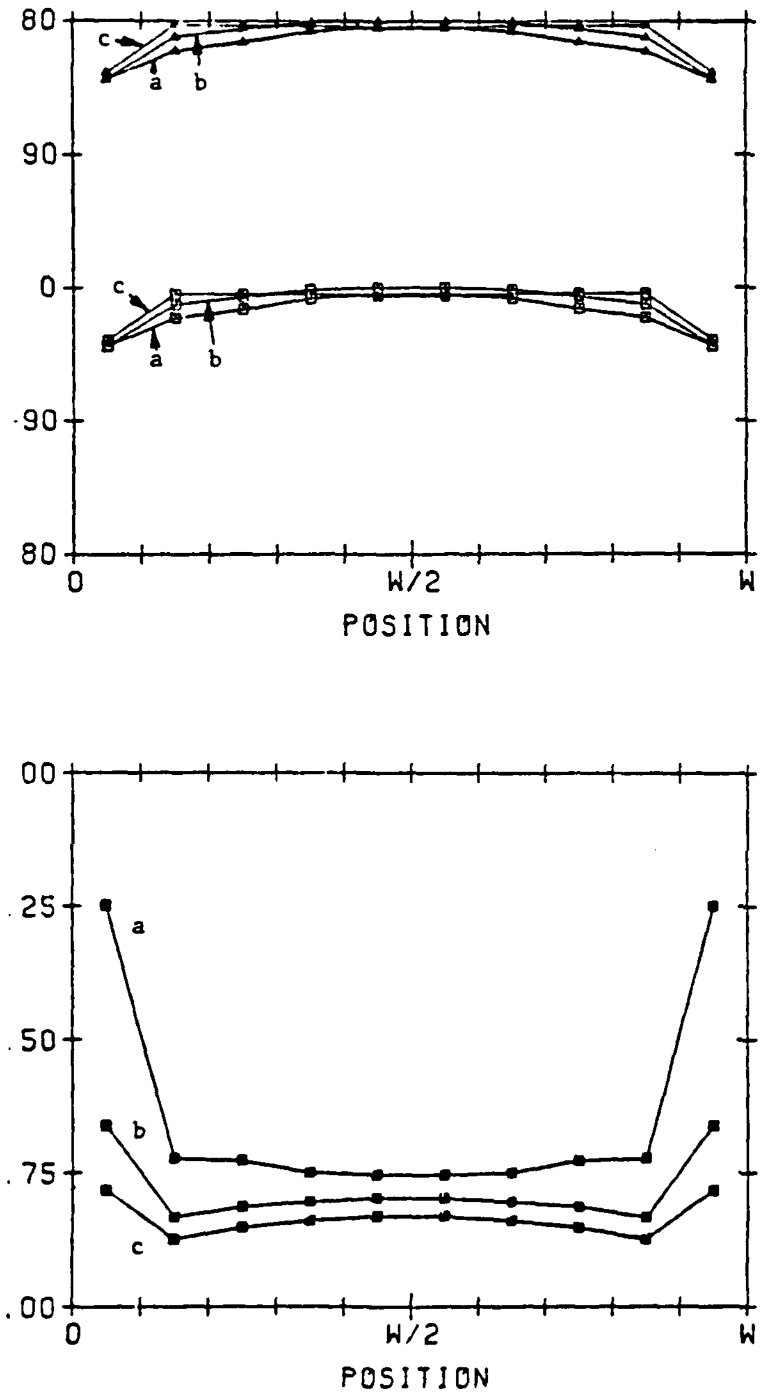


a) Thin Dielectric Sheet

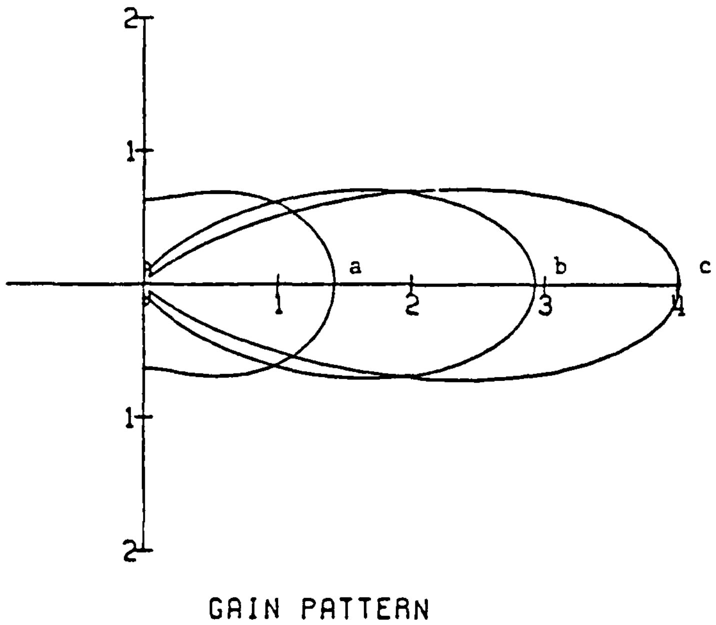


b) Thick Material Sheet

Figure 2.5.6 Approximate Network Equivalents for the Sheet-covered Aperture



;. 6. Magnitude and phase of $\overline{M}_1$ (squares) and $\overline{M}_2$ (triangles) for slit $w = .4\lambda_a$, $d = .001\lambda_a$, $k_b = k_a = k_o$ and a) $\varepsilon_c = \varepsilon_o$; b) $\varepsilon_c = 5\varepsilon_o$; c) $\varepsilon_c = 10\varepsilon_o$. $N = 10$.



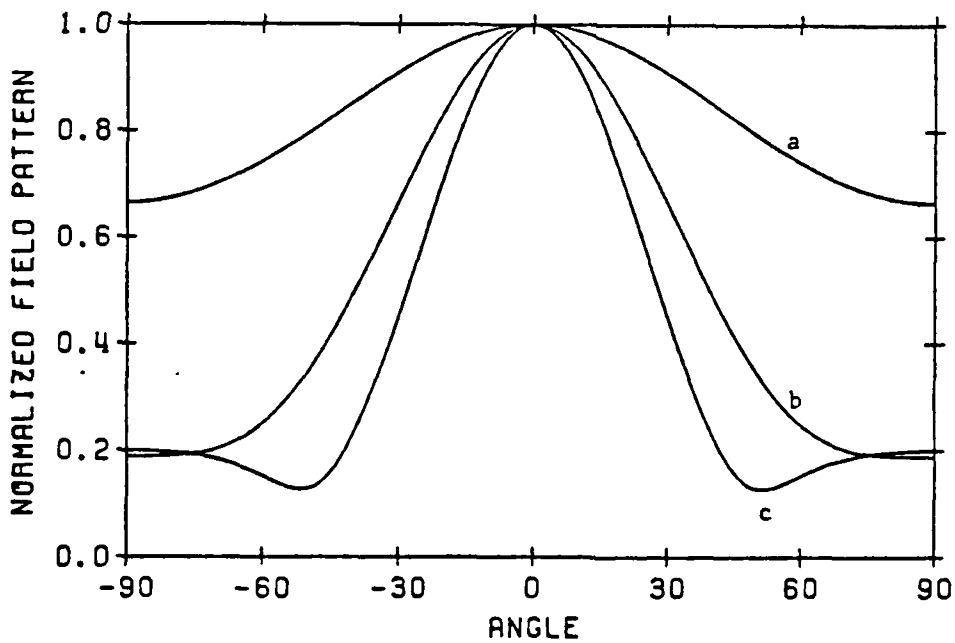


Fig. 8. Gain and normalized field patterns for slits in Fig. 6.

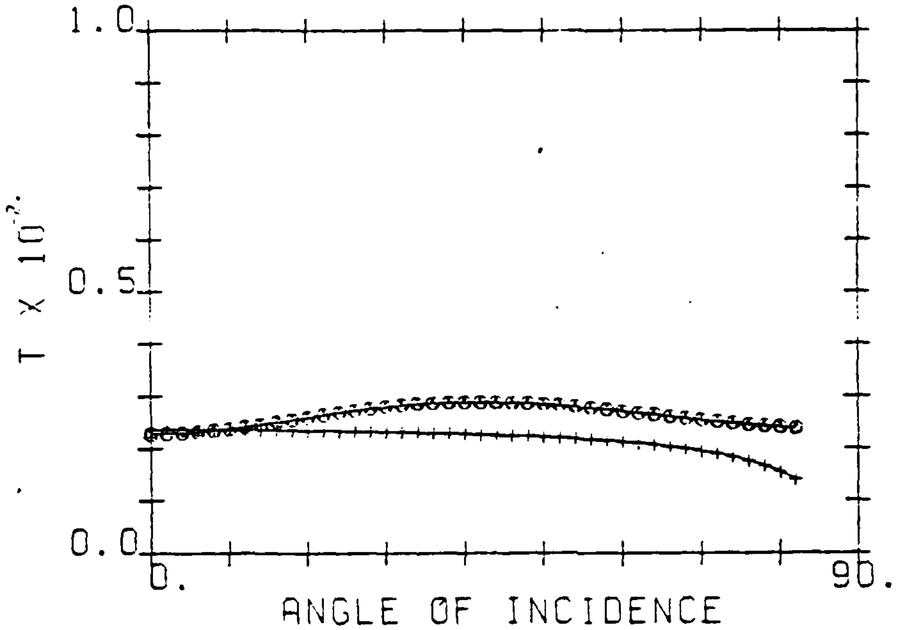


Fig. 5. Transmission coefficient when $w = 1\lambda_0$, $d = .01\lambda_0$, $\sigma = 10$ ℧/m. Circles use method in [4], triangles use plane wave assumption, +'s use infinite slab transmission coefficient.

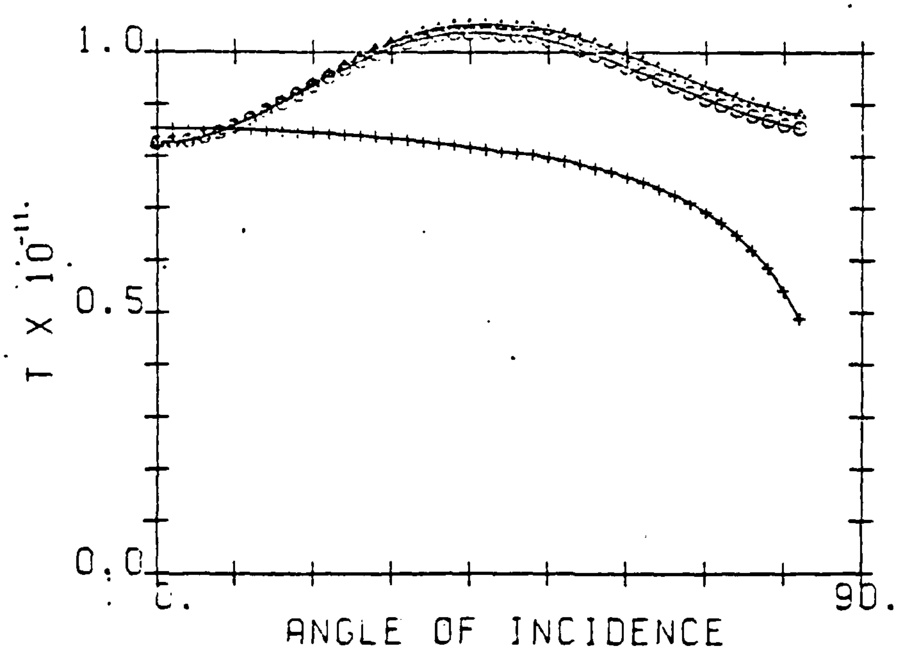


Fig 6. Transmission coefficient when $w = 1\lambda_0$, $d = .1\lambda_0$, $\sigma = 10$ ℧/m. (skin depth $= 9.19 \times 10^{-3}$ m)

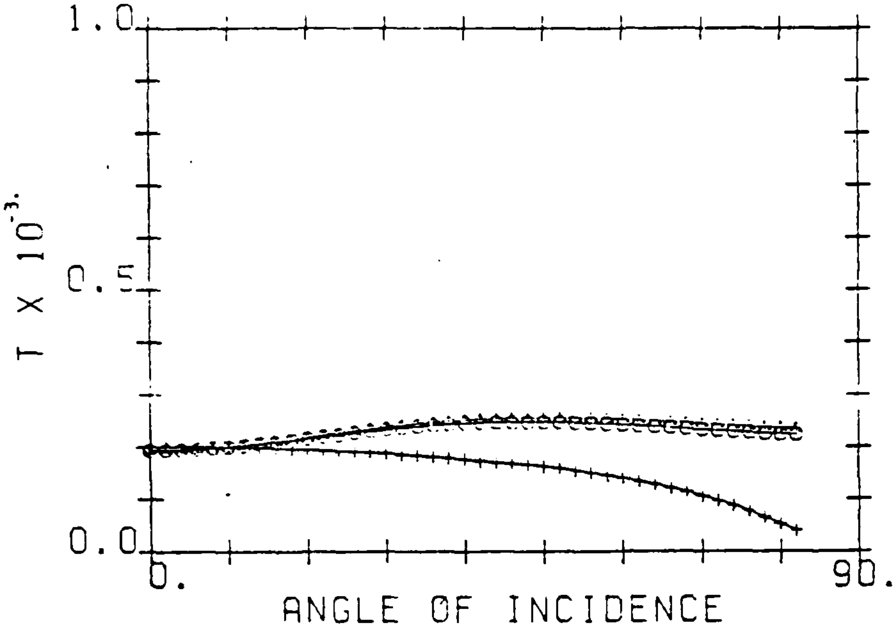


Fig 7. Transmission coefficient when $w = 1\lambda_0$, $d = .1\lambda_0$, $\sigma = 1$ ℧/m. (Skin depth = 2.93×10^{-2} m)

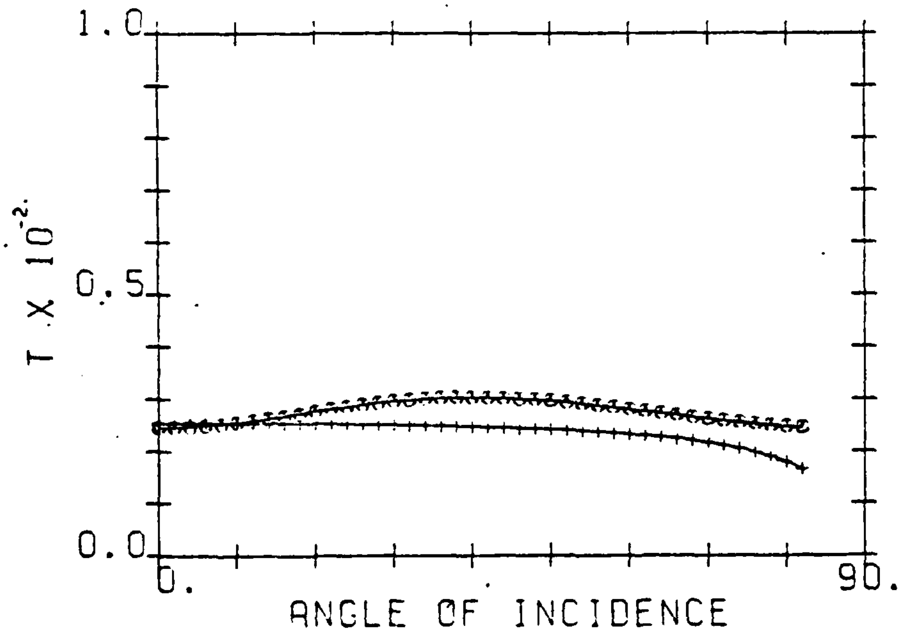


Fig 8. Transmission coefficient when $w = .1\lambda_0$, $d = .001\lambda_0$, $\sigma = 100$ ℧/m. (Skin depth = 2.9×10^{-3} m)

Robert Carri
Grumman Aerospace

AD-A096 459 NAVAL AIR SYSTEMS COMMAND WASHINGTON DC F/G 11/4
REPORT OF COMPOSITE MATERIAL AND METAL COMPOSITES JOINT WORKSHO--ETC(U)
1978

UNCLASSIFIED NL

2 OF 3

AD A
096459

MULTIPLE THREATS ADDRESSED

OPERATIONAL

- LIGHTNING
  - DIRECT
  - INDIRECT
- STATIC ELECTRIFICATION (P_{STATIC})
- ELECTROMAGNETIC INTERFERENCE (EMI)

COMBAT

- HIGH ENERGY LASER (HEL)
- NUCLEAR ELECTROMAGNETIC PULSE (NEMP)

PROGRAM OBJECTIVE

DEVELOP PRACTICAL, OPTIMIZED, AND INTEGRATED
PROTECTION AND SHIELDING METHODOLOGIES
TO PROTECT COMPOSITE AIRCRAFT STRUCTURES
AGAINST MULTIPLE THREATS

SUBCONTRACTOR TASKS

- LIGHTNING TRANSIENTS RESEARCH INSTITUTE (LTRI), ST PAUL, MINN.
  - *MODEL ATTACH. TESTS*
  - LIGHTNING, P_{STATIC} & SHIELDING TESTS
- MISSION RESEARCH CORPORATION (MRC) ALBUQUERQUE, NEW MEXICO
  - EM ANALYSIS
  - CONSULTANT ON EM TESTING
- AVCO SYSTEMS DIVISION LOWELL, MASS.
  - LASER TESTING
  - THERMAL ANALYSIS

DISTRIBUTION OF STRIKE POINTS

TEST SERIES (NO.):	1	2	3	4	5	6	7
NOSE RADOME	28%	29%	29%	31%*	28		
LOWER FUSELAGE (ANTENNAS)	7	6	6	3	8		
AFT CANOPY	1	1	1		1		
WINGTIP	40	40	38	40	30	69	67
CANARD	1	1	1	1	3	4	
VERTICAL FIN	13	13	15	17*	17*	27	33
TAIL CONE	10	10	10	8	3		
TOTAL PERCENT	100	100	100	100	100	100	100
TOTAL DISCHARGES	72	72	72	72	72	101	18

*SLIGHTLY GREATER NUMBER OF STRIKES TO NOSE RADOME AND VERTICAL FIN COULD BE ARGUED AS INDICATING THAT STROKES ARE BEING DRAWN INTO AREA BY GRAPHITE VERTICAL FIN INSERT AND GRAPHITE FORWARD FUSELAGE, BUT THEY ARE NOT SUFFICIENTLY DIFFERENT TO BE STATICALLY SIGNIFICANT WITHOUT MANY MORE TESTS IN THE CRITICAL AREA.

NOTE: TOTAL NUMBER OF TEST DISCHARGES – 517, INCLUDING ABOVE SEQUENCES PLUS SETUP TESTS AND RERUNS.

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NUCLEAR ELECTROMAGNETIC PULSE (EMP) THREAT

WEAPON:

NUCLEAR DEVICE OF KNOWN YIELD AND BURST ALTITUDE

EFFECTS:

- EXTERNAL COUPLING – CONVENTIONAL AIRCRAFT RESPONDS TO EMP AS AN ANTENNA; SURFACE CURRENTS AND CHARGES ARE INDUCED ON AIRCRAFT
- ELECTROMAGNETIC FIELDS PENETRATE THE AIRCRAFT VIA POINTS OF ENTRY (POE)
  - DIRECT DIFFUSION THRU AIRCRAFT SKIN
  - DELIBERATE ANTENNAS DESIGNED TO PICK UP THE ENERGY
  - INADVERTENT PENETRATIONS
- INTERNAL COUPLING – EM ENERGY IS COUPLED TO INTERNAL CONDUCTORS BY MEANS OF POE, AND PROPAGATES TO ELECTRONIC BOXES

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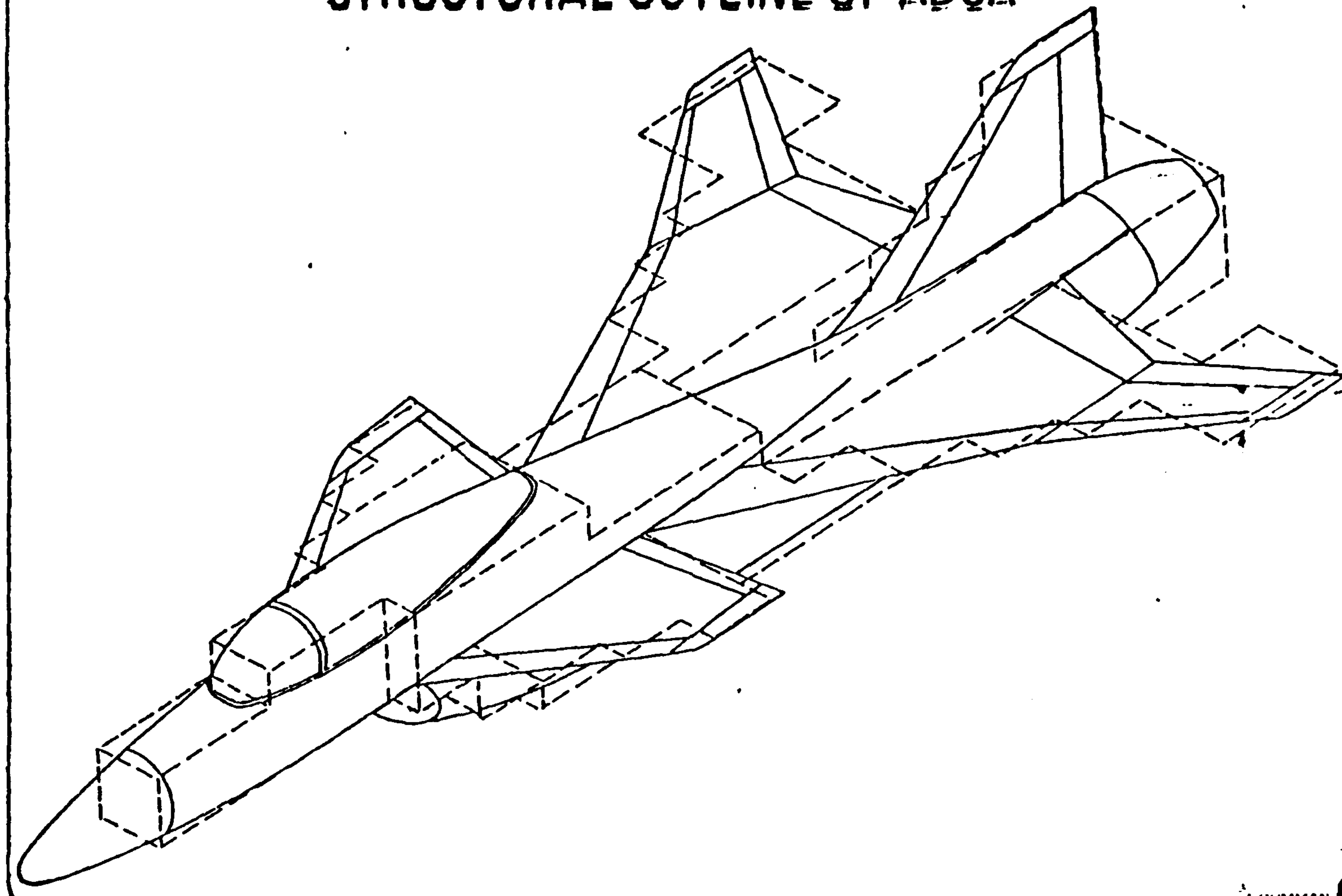
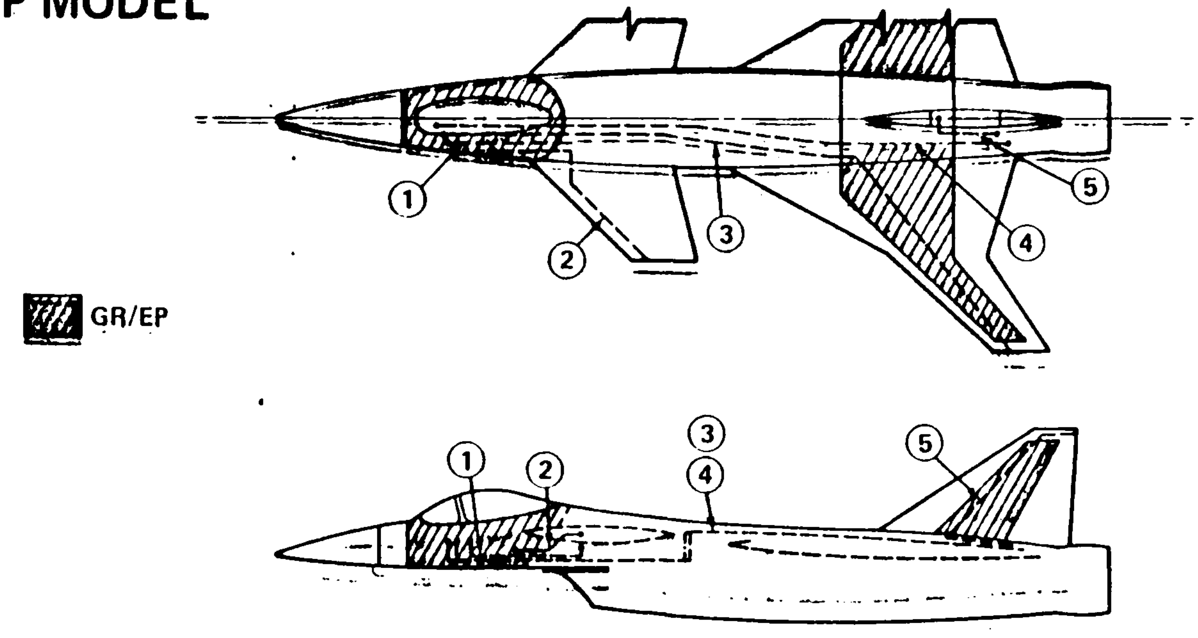
OVERLAY OF THREDE MATHEMATICAL MODEL AND STRUCTURAL OUTLINE OF ADCA



EMP MODEL



1. ENV. CONTR. SYSTEM – TWISTED PAIR – UNSHIELDED – 22 GA.
2. ANTENNA – COAX CABLE – RG 214
3. SIDEWINDER – CABLE
4. FLY BY WIRE – CABLE
5. ANTENNA – COAX CABLE – RG 214

SIDEWINDER CABLE

26 GA – SHIELDED (1)
22 GA – TWISTED – NO SHIELD (3)
22 GA – NO SHIELD (1)

FLY–BY–WIRE CABLE

22 GA – NO SHIELD (1)
26 GA – SHIELDED TWISTED PAIR – SHIELD GROUNDED AT BOTH ENDS – CIRCUIT GROUNDED IN COCKPIT (1)
26 GA – SHIELDED TWISTED PAIR SHIELD GROUNDED AT ONE END IN COCKPIT-CIRCUIT GROUNDED IN COCKPIT (1)

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MATH Model / AOCA

NEMP - ANALYSIS RESULTS

WORST CASE CABLE RESPONSES

	CONDUCTIVITY MHO/M	OPEN CIRCUIT VOLTAGE (V)	SHORT CIRCUIT (CURRENT (MA)
CANARD - ANTENNA (SHIELDED CABLE)	8000	14	149
	15000	4.8	61
	20000	3.1	41
HARNESS (FLY BY WIRE)	8000	110	297
ECS TWISTED PAIR	15000	47	203
SIDEWINDER CABLE	20000	41	162

EXPERIMENTAL DATA EXTRAPOLATED TO THREAT LEVEL
(A7E AIRCRAFT - 45 FOOT FUSELAGE APERATURE COUPLING)

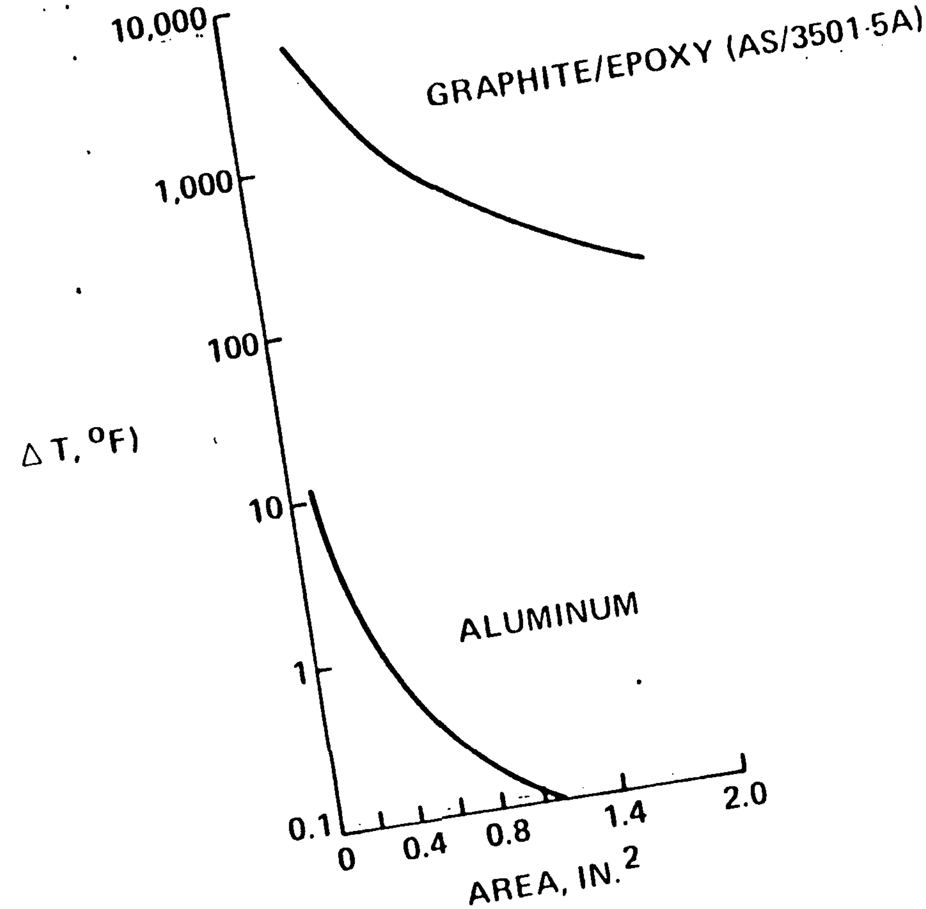
BETWEEN 370 MA AND 3.3 AMPS AVIONICS BAY (11 CABLES)
BETWEEN 920 MA AND 8.3 AMPS CABLES FROM WING (10)

VARI[illegible] GAGE thick[illegible] Cable.

Vari[illegible] in [illegible] short c[illegible] termi[illegible]

Variable & Axi[illegible] (Vari[illegible] Charact[illegible] Impede[illegible]

V


GRAPHITE/EPOXY (AS/3501-5A)
ALUMINUM
ΔT, °F)
10,000
1,000
100
10
1
0.1
0
0.4
0.8
1.4
2.0
AREA, IN.2

12

ATEGORY	TYPE	VENDOR(1)	ULTIMATE TENSILE STRENGTH, KSI	TENSILE MODULUS PSI X 10^6	DENSITY, GM/CC	AVAIL-ABILITY(3)
olycrystalline						
umina	FP-1	D	200	55	3.7	L
	FP-2	D	250	55	3.7	L
ramid	KEVLAR 29	D	550	9	1.44	P
	KEVLAR 49	D	550	19	1.45	L
oron (2)	4 MIL/W	A,CTI	475	58-60	2.60	P
	5.6 MIL/W	A,CTI	500	58-60	2.48	L
	4 MIL/CC	A	400	50	2.10	L
lass	"E"	-	500	10.5	2.54	P
	"S"	-	650	12.4	2.49	L
aphite (Low-Cost, High-rength) HS)	CELION	C	419	34	1.75	P
	A-S	H	420	34	1.81	P
	T-300	U	360	33	1.76	P
	TYPE III	M	350	33	1.78	L
	3T	G	300	30	1.8	P
termediate dulus IM)	T-400	U	425	33	1.78	L
	TYPE II	M	360	40	1.71	D
	HTS	H	410	36	1.82	L
	4T	G	350	38	1.80	D
igh Modulus (HM)	HM	H	350	53	1.89	L
	T-50	U	300	57	1.87	L
	TYPE I	M	350	56	1.86	L
	5T	G	400	48	1.85	L
	6T	G	420	58	1.90	L
tra-High odulus (UHM)	GY-70	C	250	75	1.86	P
licon (2) rbide	4 MIL/W	A,CTI	480	62	3.41	D
	4 MIL/CC	A,CTI	480	62	2.99	D
	5.6 MIL/CC	A,CTI	480	62	3.07	D

(1) A - AVCO
C - Celanese
CTI - Composite Technology, Inc.
D - Dupont
G - Great Lakes
H - Hercules
M - Marganite
U - Union Carbide

(2) W - Tungsten Core
CC - Carbon Core

(3) P - High Rate Production
L - Limited Production
D - Developmental Status

FIBER PROPERTIES AND AVAILABILITY

RELATIVE COST AND WEIGHT FACTORS OF POPULAR PROTECTION SYSTEMS

	WT LBS/SQ FT	MAT'L COST	LABOR COST
1100 AL ALLOY FLAME SPRAY $t \approx$ 6 MILS $\rho \approx 1 \times 10^6$ MHOS/M	1	1	1
5056 AL ALLOY 120 GRID WIRE MESH $\rho \approx .7 - 2.0$ MHOS/M	1.37	14.3	1.6
2024 AL ALLOY 4 MIL FOIL	1.14	6	1.3

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STRUCTURAL FASTENERS AND APPLICATIONS

INTERFERENCE FIT

- BUCKED RIVETS = USE NOT PERMITTED FOR COMPOSITES (UNCONTROLLED EXPANSION)
- TAPER LOKS = HIGH INSTALLATION COSTS
- STRESS WAVE RIVETING = GAC DEVELOPED (CONTROLLED EXPANSION)
- BF GOODRICH RIVNUT = WET WINGS (ELIMINATED "O" RING SEAL)

BOLTS - CLOSE TOLERANCE = IN GENERAL THEY DO NOT PROVIDE INTIMATE CONTACT WITH GRAPHITE FIBERS

- ACCESSIBLE = HI LOKS, HI TORQUE RECESS ETC
- BLIND - JO BOLT, HUCK BOLT (COMPOSITE TO METAL)
  - BIG FOOT (COMPOSITE TO COMPOSITE)

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CONDUCTIVITY OF TYPE AS GRAPHITE EPOXY LAMINATES

LAMINATE	NO. PLIES	LAYUP, %			REFERENCE	CONDUCTIVITY 10^3 Mhos/METER			EQUIVALENT % 0° LAMINATE
		0°	90°	±45°		MAX	MIN	AVG	
$[0, \pm45, \mp45, 0]_T$	6	33	0	67	1	20.1	17.0	18.2	66
$[90, \pm45, \mp45, 90]_T$	6	0	33	67	1	10.1	7.1	9.1	33
$[0, \pm45, \pm45, \pm45, \pm45, 0]_T$	10	20	0	80	1	16.5	14.1	15.2	60
$[\pm45, 90, 90, \mp45]_T$	6	0	33	67	2	10.5	8.8	9.7	33
$[90, 90, 0, 0, 90, 90]_T$	6	33	67	0	2	11.2	10.2	10.7	33
$[\pm45, 0, 0, \pm45]_T$	6	33	0	67	2	18.9	14.4	16.7	66
$[0, 0, 90, 90, 0, 0]_T$	6	67	33	0	2	17.9	16.3	17.1	67
$[0, \pm45, \pm45, 0]_T$	6	33	0	67	3	23.4	19.0	21.5	67
$[0, \pm45, \pm45, \pm45, \pm45, 0]_T$	10	20	0	80	3	17.8	16.6	17.8	60
$[90, \pm45, \pm45, 90]_T$	6	0	33	67	3	9.8	9.2	9.6	33
$[0_{12}]_T$	12	100	0	0	GAC	36.6	34.6	35.6	100
$[\pm45, 0_8, \pm45]_T$	12	67	0	33	GAC	29.4	28.5	29.0	83
$[\pm45, 90, 0_6, 90, \pm45]_T$	12	50	17	33	GAC	23.8	22.5	23.2	67
$[\pm45_2, 90, 0_2, 90, \pm45_2]_T$	12	17	17	67	GAC	12.8	12.5	*12.7	50
$[\pm45_6]_T$	12	0	0	100	GAC	17.5	17.4	17.5	50
$[\pm45, 90_3, \pm45, 90_3, \pm45]_T$	12	0	50	50	GAC	7.7	5.4	*6.6	25

*TESTED AT AN EARLIER DATE USING LESS ACCURATE CONNECTION TECHNIQUES

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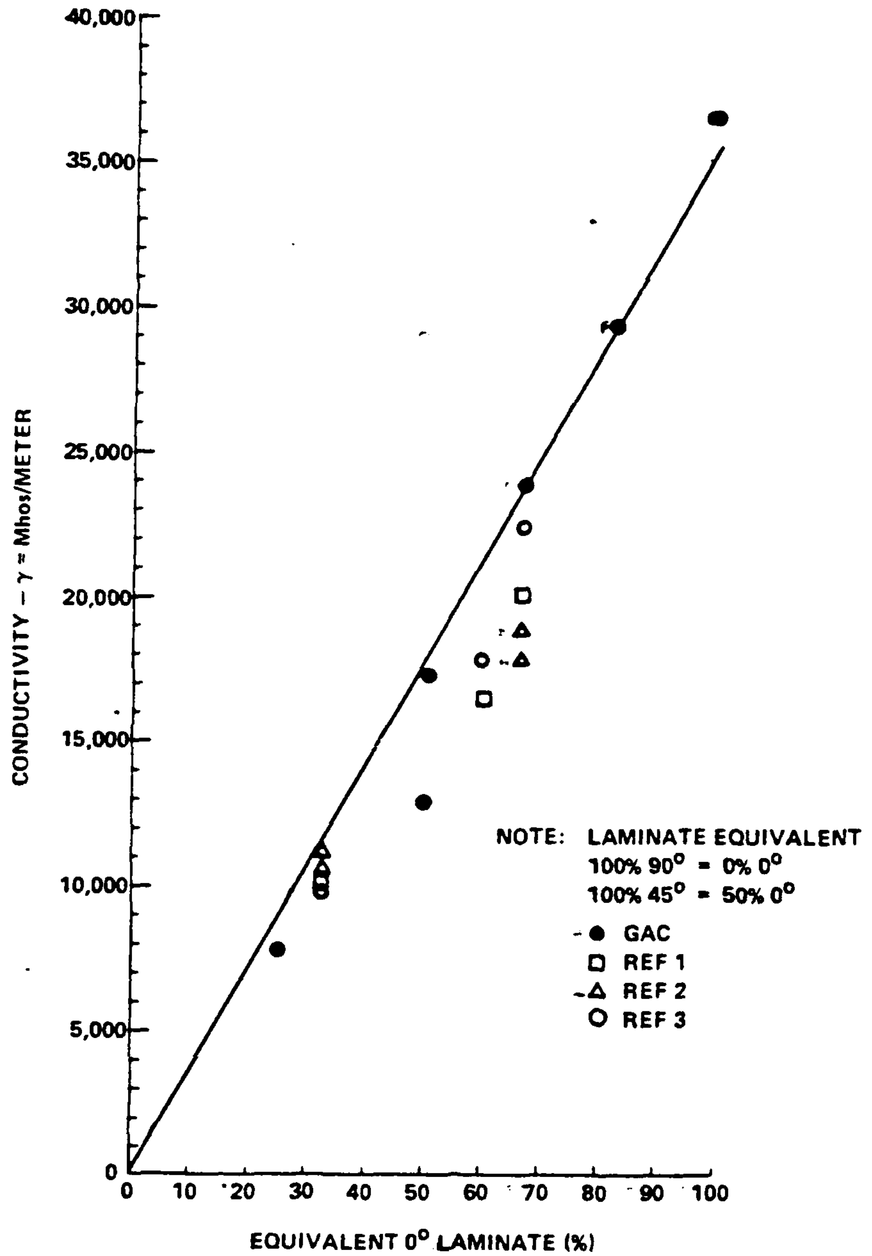
MAC /
Boeing
GD

RELATIVE CONDUCTIVITY VALUES FOR GR/EP LAMINATES

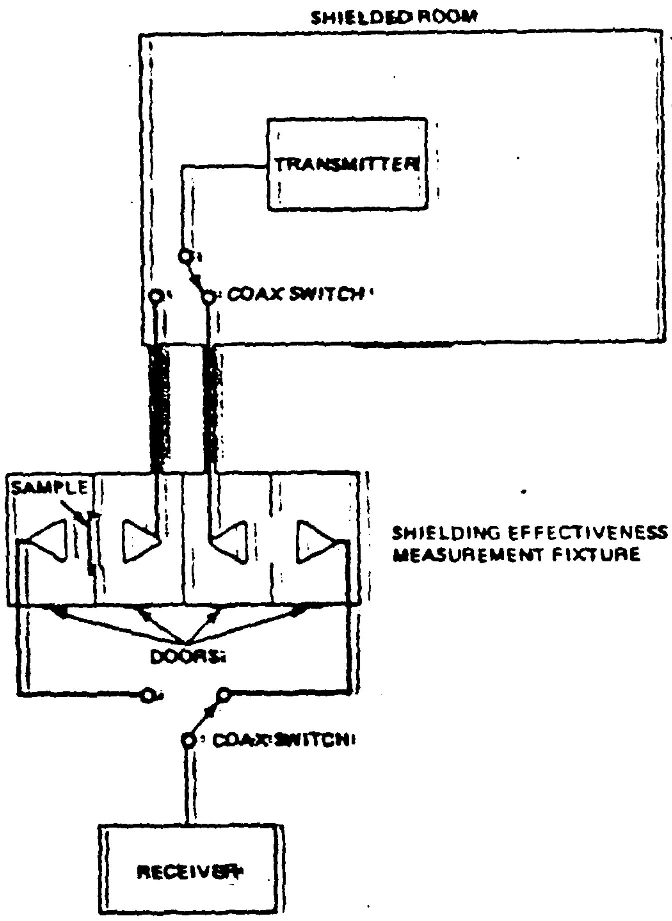


SHIELDING EFFECTIVENESS MEASUREMENTS - FLAT PLATE FACILITY

- FOUR COMPARTMENT FIXTURE - ONE PAIR OF COMPARTMENTS USED TO OBTAIN A REFERENCE WITH OPEN APERTURE - OTHER PAIR OF COMPARTMENTS HAS A MOUNTED SAMPLE IN THE APERTURE DIFFERENCE IN dBs IS THE SHIELDING EFFECTIVENESS OF THE MATERIAL BEING TESTED

- EACH PAIR OF ANTENNAS CHECKED FOR EQUIVALENCY TO INSURE CONDITIONS ARE THE SAME IN EACH PAIR OF COMPARTMENTS PRIOR TO TEST

- TRANSMITTER, RECEIVER AND ANTENNA EQUIPMENT USED DEPENDENT ON TYPE OF FIELD AND FREQUENCY RANGE



Shielding Effectiveness Measurement Set-Up

FIXTURE DESIGN

- ALL-WELDED ALUMINUM
- ALL APERTURES BOTH INTERNAL AND EXTERNAL HARDENED BY A 1/4 X 3/16 INCH RF METAL GASKET AT A DISTANCE OF 1/2 INCH FROM THE EDGE OF OPENING IN A RIGID MACHINED RECESSED GROOVE
- EXTERNAL DOORS - UQ904 TYPE MANUFACTURED BY UNIVERSAL SHIELDING CORPORATION
- NO THRU BOLT HOLES IN FIXTURE

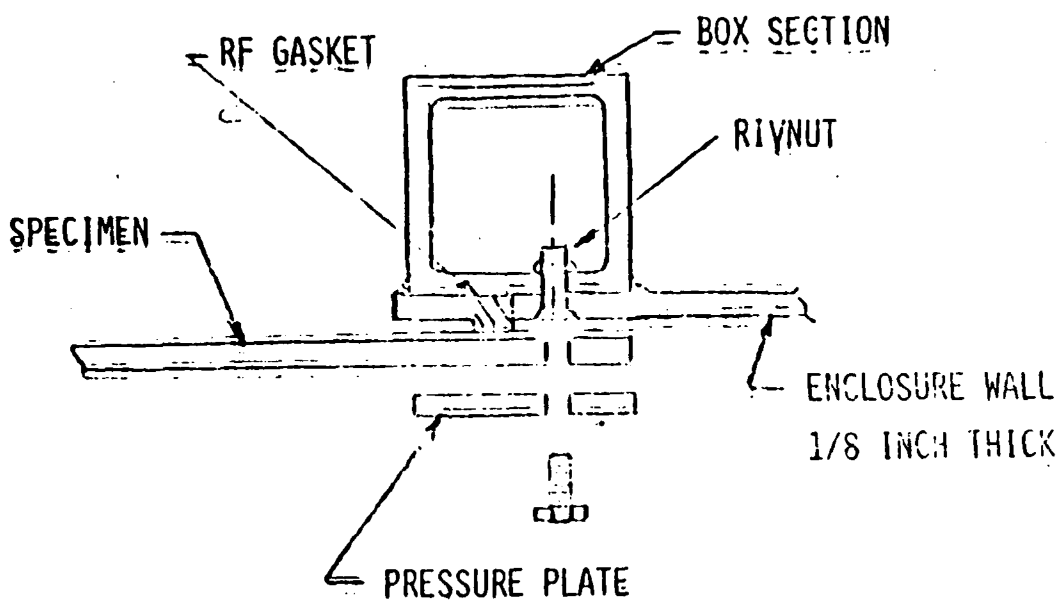
SPECIMEN PREPARATION

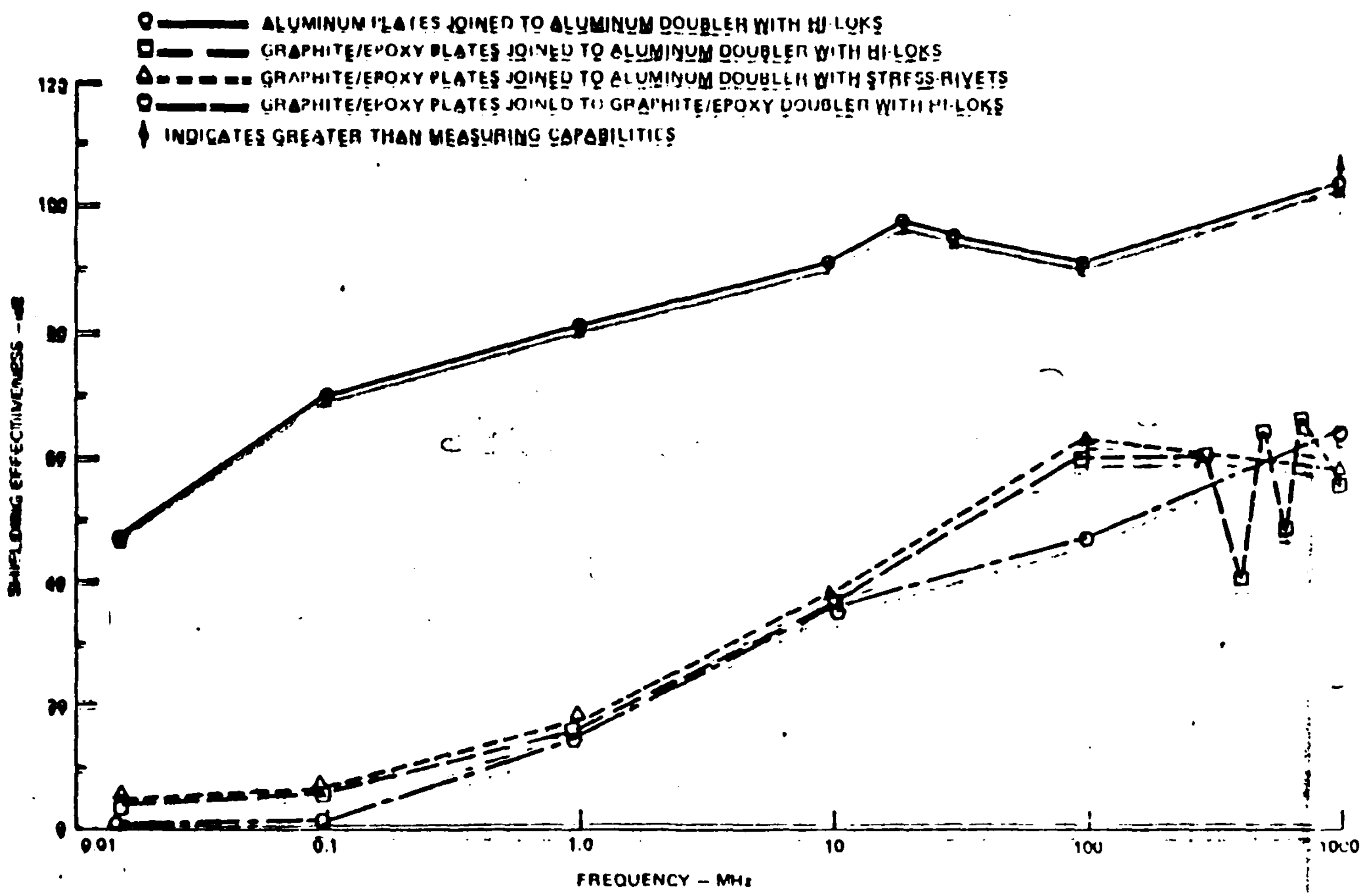
- SPECIMENS - (15 X 15 INCHES) TAPER GRIND EDGED AND PERIPHERAL FRAME WITH 1 1/2 INCH ALUM STRIP (BOTH SIDES) BONDED ON WITH A CONDUCTIVE ADHESIVE (SILVER FILLED EPOXY)
- PREDRILL SAMPLE

SPECIMEN MOUNTING

- INSTALL 15 X 15 INCH SAMPLE IN 12 X 12 APERTURE WITH AN ALUMINUM FRAME (PRESSURE PLATE) ON THE OUTER SURFACE 3/16 DIA FASTENERS, 1 INCH PITCH

DETAIL OF SPECIMEN MOUNTING





8040-111W

Figure 3-7 Magnetic Shielding Effectiveness of Tightly Joined Panels

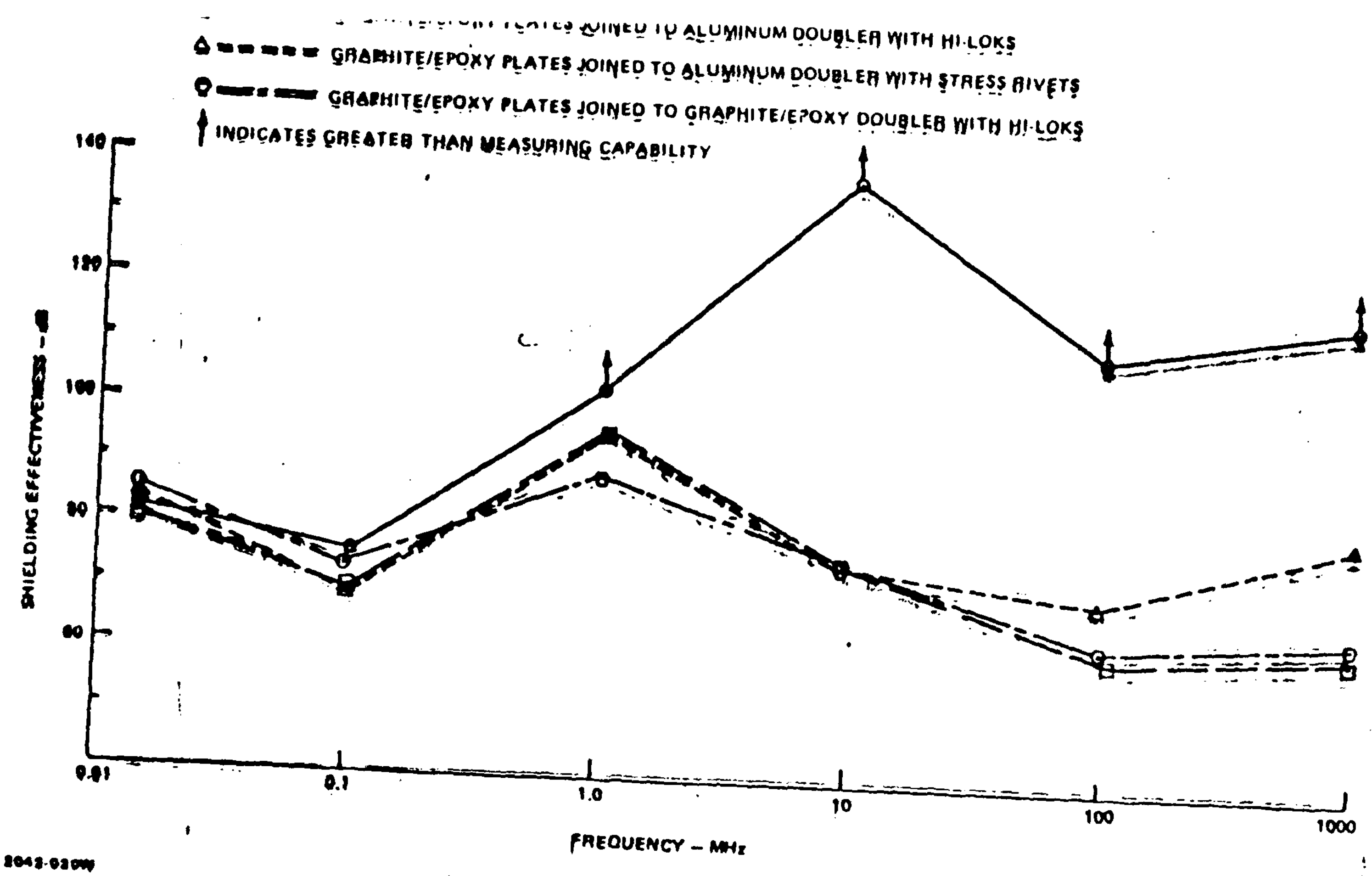


Figure 3-8 E-Field Shielding Effectiveness of Tightly Joined Panels

SHIELDING EFFECTIVENESS MEASUREMENT EQUIPMENT LIST

FREQUENCY RANGE	TRANSMITTER	TRANS ANTENNA	RECEIVER	REC ANTENNA	TYPE OF FIELD
10 KHz TO 32 MHz	H.P. 206 AG SIG GEN	LOOP	SINGER NM-17/27	LOOP	LOW IMP (H)
10 KHz TO 32 MHz	H.P. 606 SIG GEN	ROD	NM-17/27	ROD	HIGH IMP (E)
32 MHz TO 200 MHz	PLUS I.F.I. 5000	LOOP	SINGER NM-37/57	LOOP	(H)
32 MHz TO 200 MHz	AND I.F.I. M402 PWR AMP	ROD	↓	ROD	(E)
200 MHz TO 500 MHz	H.P. 608 SIG GEN	LOOP	↓	LOOP	(H)
200 MHz TO 500 MHz	AND H.P. 230 PWR AMP	ROD	↓	ROD	(E)
500 MHz TO 1 GHz	H.P. 612 SIG GEN	LOOP	↓	LOOP	(H)
500 MHz TO 1 GHz	↓	ROD	↓	ROD	(E)
1 GHz TO 2 GHz	H.P. 614 SIG GEN AND KELTEC LR605-10	LOOP	EMPIRE NF-112	LOG PERIODIC	(H)
		ROD	↓	↓	(E)
2 GHz TO 4 GHz	H.P. 618 SIG GEN AND H.P. 419C	LOOP	↓	↓	(H)
		ROD	↓	↓	(E)
4 GHz TO 7.6 GHz	H.P. 618 SIG GEN AND H.P. 493A	LOOP	↓	↓	(H)
		ROD	↓	↓	(E)
7.6 GHz TO 10 GHz	H.P. 620 SIG GEN AND H.P. 495A	LOOP	↓	↓	(H)
		ROD	↓	↓	(E)

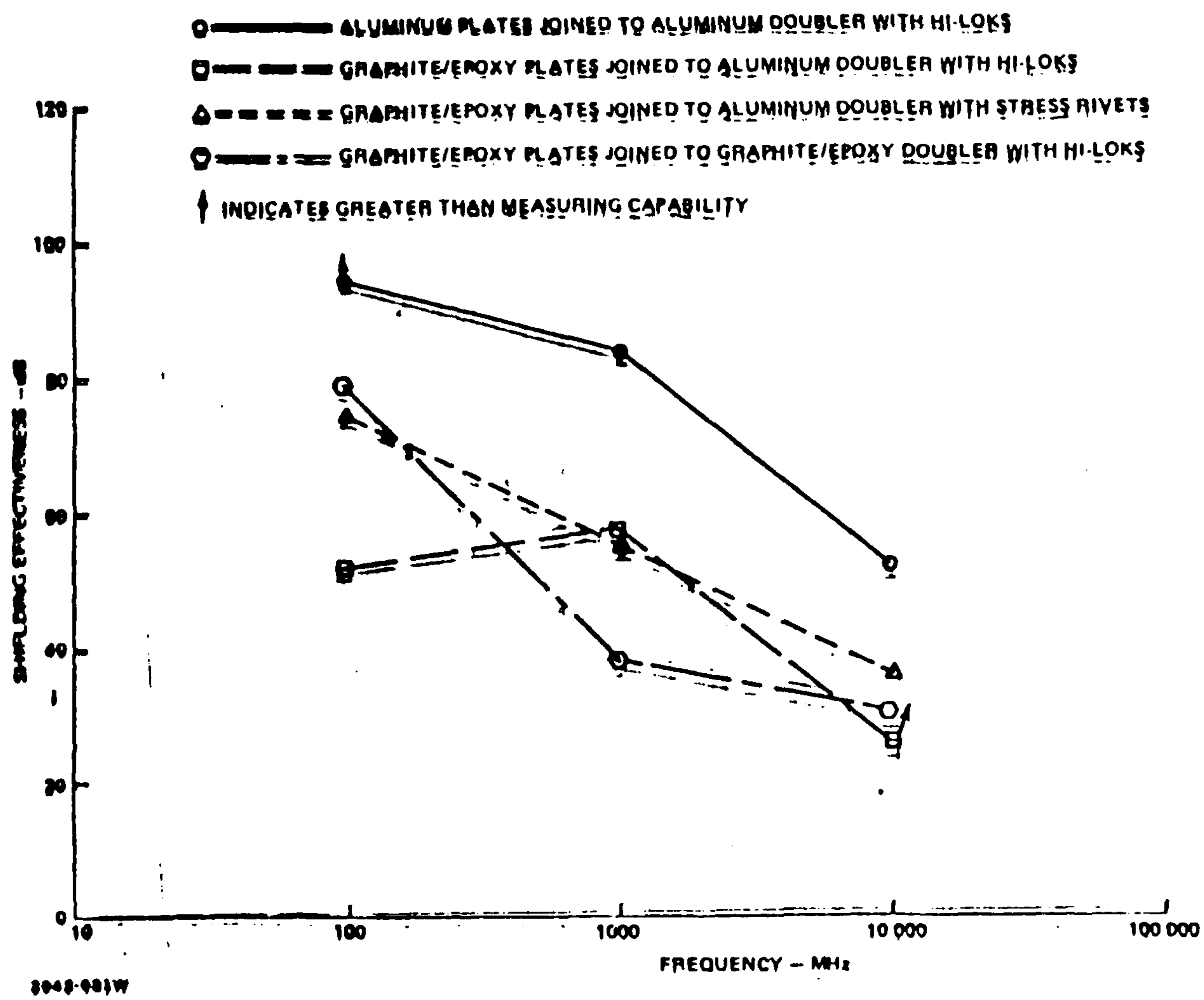


Figure 3-8 Plane-Wave Shielding Effectiveness of Tightly Joined Panels

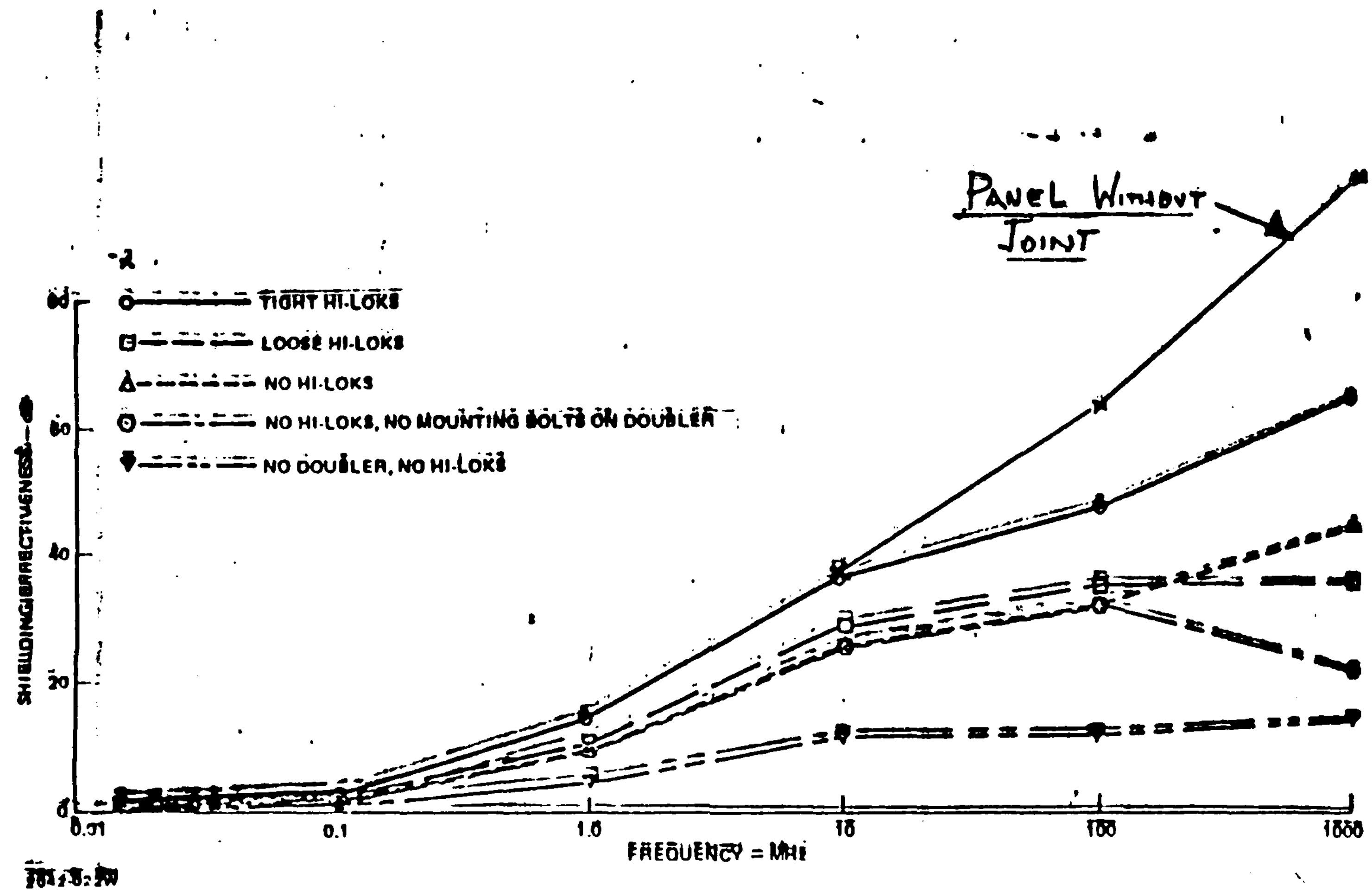
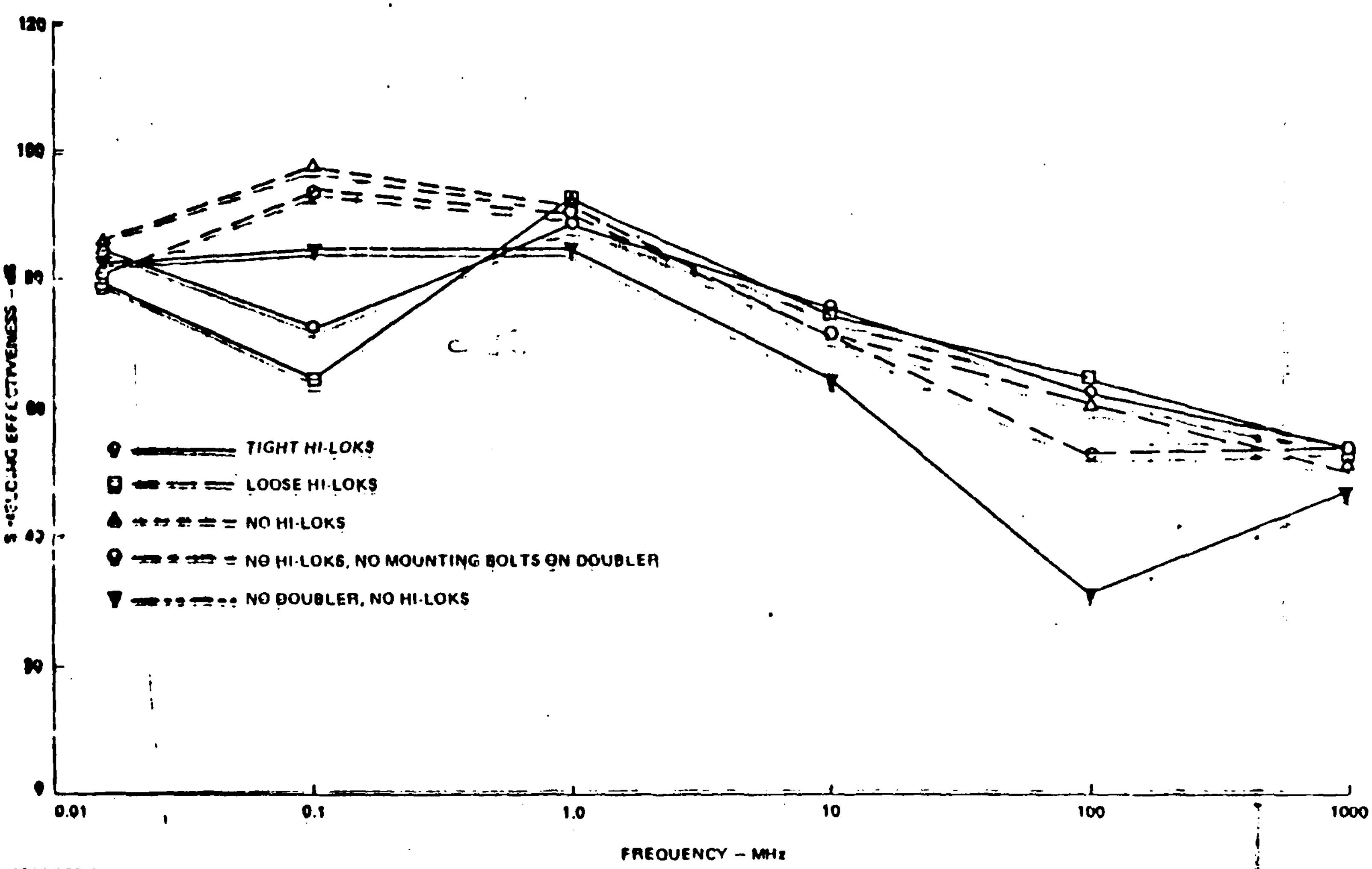


Figure [illegible]. Variation of Magnetic Shielding Effectiveness of 2/2/8 Graphite/Epoxy Panels Joined to 24 Ply Graphite/Epoxy Doubler With Hi-Loks



2042-023W

Figure 3-11 Variation of E-Field Shielding Effectiveness of 2/2/8 Graphite/Epoxy Panels Joined to 24 Ply Graphite/Epoxy Doubler With Hi-Loks

2-1

25

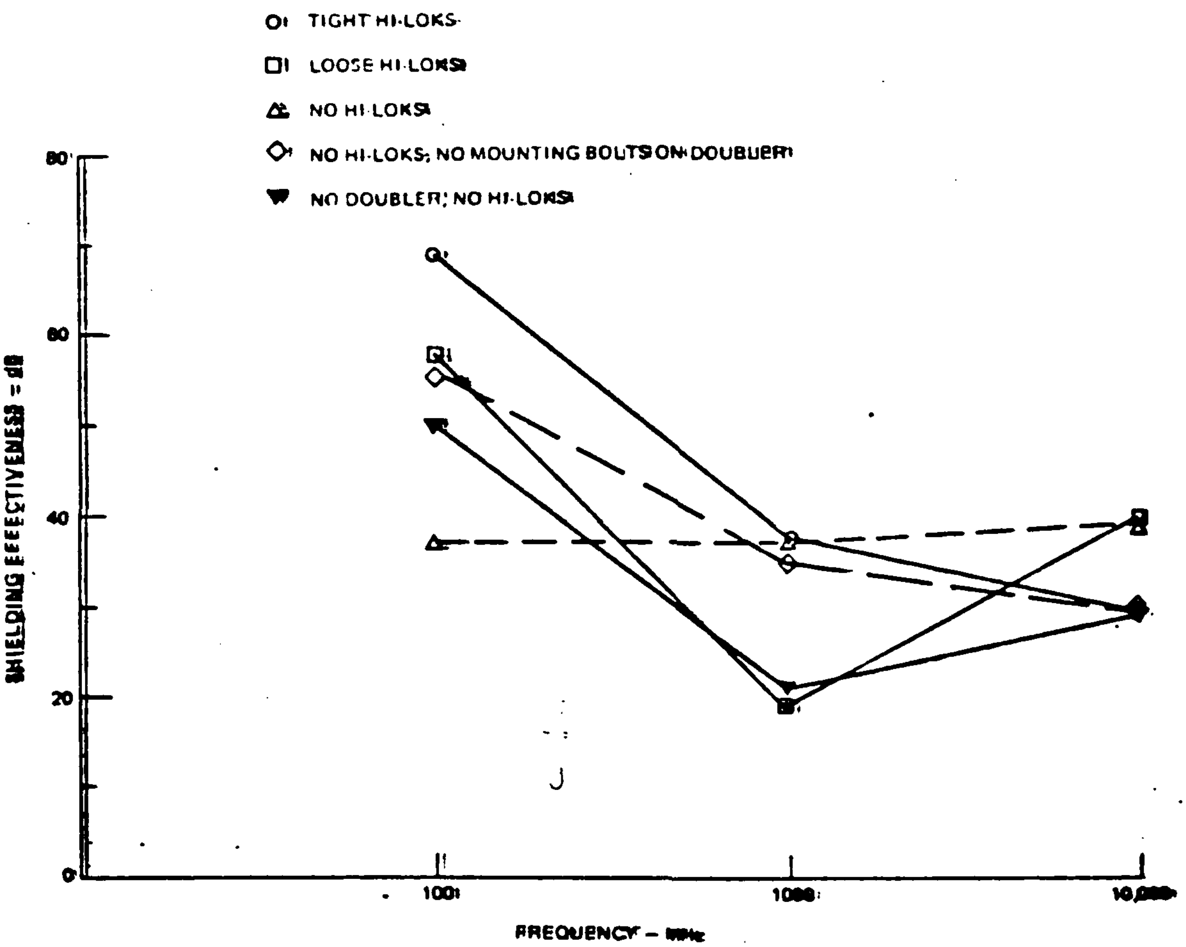


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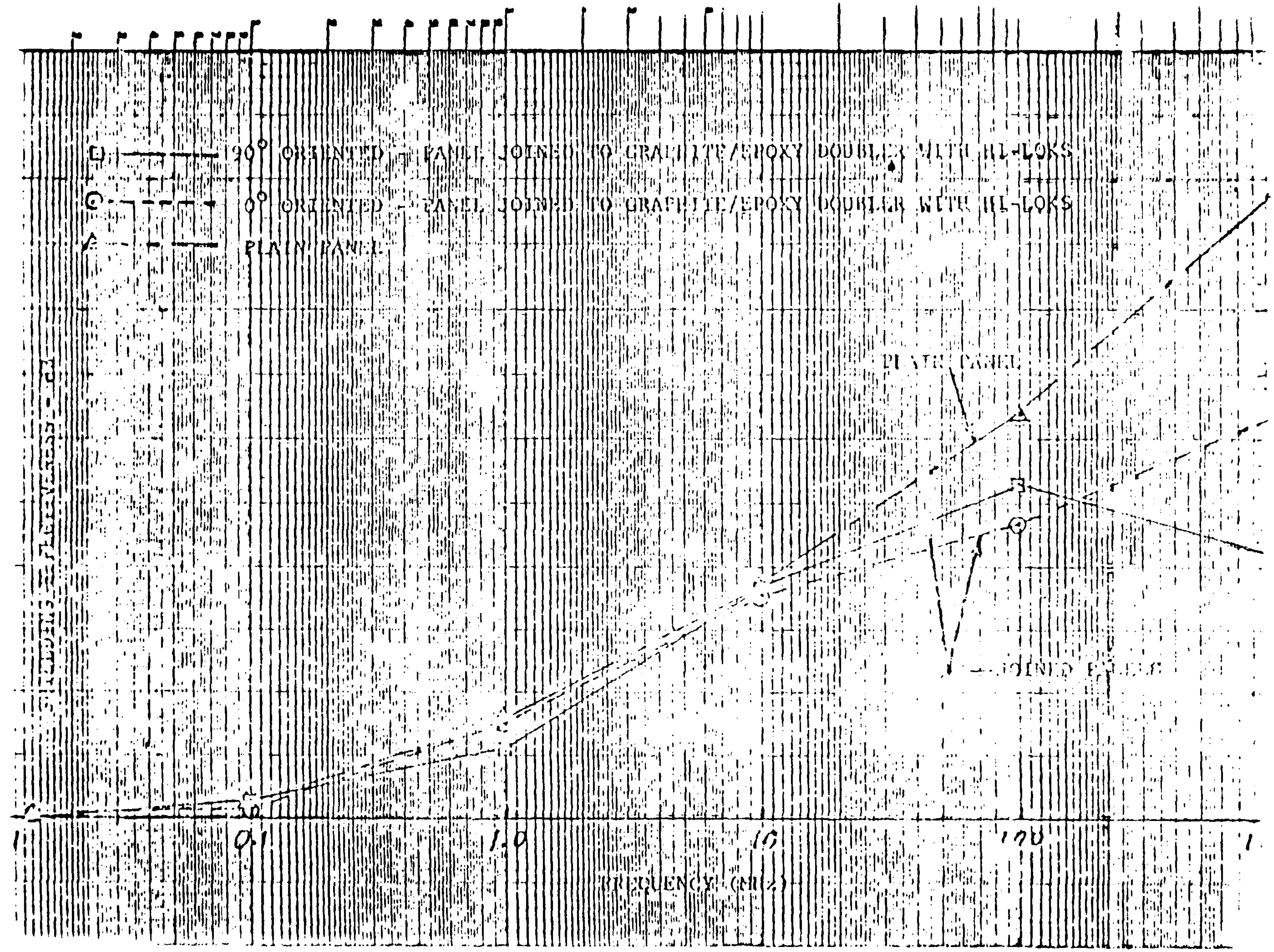
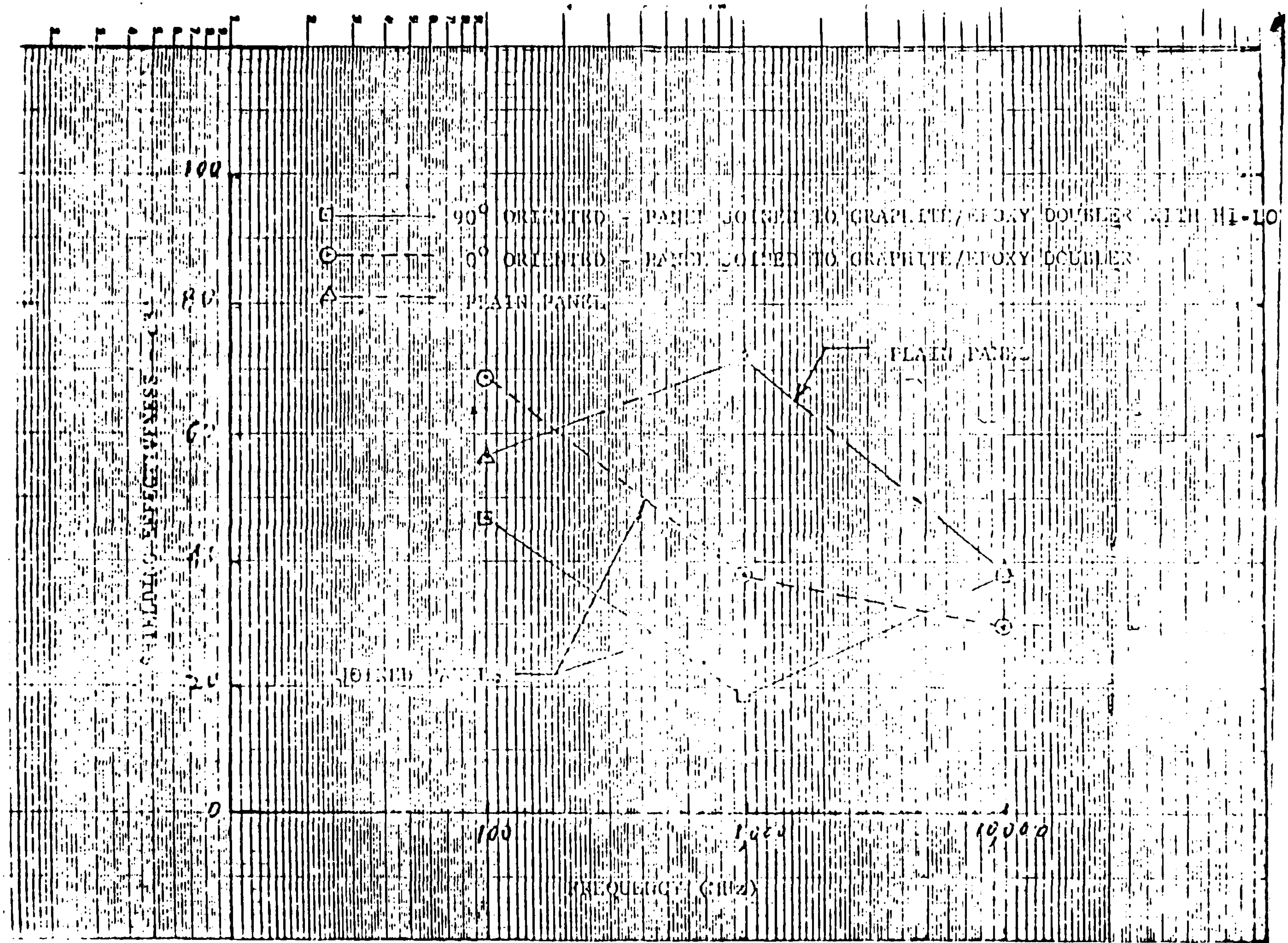
Figure 3-12 Variation of Plane-Wave Shielding Effectiveness for 2/2/8 Graphite/Epoxy Panels Joined to 24 Ply Graphite/Epoxy Doubler With Hi-Loks



90° ORIENTED - PANEL JOINED TO GRAPHITE/EPOXY DOUBLER WITH HI-LOKS
0° ORIENTED - PANEL JOINED TO GRAPHITE/EPOXY DOUBLER WITH HI-LOKS
PLAIN PANEL
PLAIN PANEL
JOINED PANELS
0.1
1.0
10
100
FREQUENCY (MHz)



EPOXY PLAIN AND JOINED PANELS

49

POAC ACCOMPLISHMENTS TO DATE

- CONDUCTIVITY OF GRAPHITE/EPOXY MULTI-DIRECTIONAL LAMINATES SIMPLIFIED ENGINEERING APPROACH SUBSTANTIATED BY TEST
- LIGHTNING STRIKE MODEL STUDIES COMPLETED
- NEMP COUPLING ANALYSIS COMPLETED
- DEVELOPED PARALLEL RESISTOR ANALOGY FOR ANALYTICALLY OBTAINING SHIELDING EFFECTIVENESS FOR GR/EP LAMINATES WITH A PROTECTION SYSTEM
- LEMP COUPLING ANALYSIS - NINETY PERCENT COMPLETED
- POAC COMPUTER PROGRAM - THIRTY PERCENT COMPLETED
- THREAT MATRIX - EIGHTY PERCENT COMPLETED
- SPARK PROOF WING TANK - AWAITING TEST AT LTRI
- COMPOSITE JOINTS - SHIELDING DATA - TWENTY PERCENT COMPLETED
- COMPLETED SWEPT STROKE TESTING ON FLAT PANELS
- DEVELOPED PROCESS FOR SECONDARY APPLICATION OF ALUMINUM FLAME SPRAY ON CURED GR/E STRUCTURE

GRUMMAN

*DESIGN AND MEASUREMENT OF STRUCTURAL/ELECTRICAL
COMPOSITE AIRFRAME JOINTS

PRESENTED TO

COMPOSITE MATERIAL AND METAL-COMPOSITE
JOINT WORKSHOP MEETING

PREPARED FOR

NAVAL AIR SYSTEMS COMMAND
WASHINGTON, D.C.

PREPARED BY

GRUMMAN AEROSPACE CORPORATION
BETHPAGE, NEW YORK

AUGUST 24, 1978

*WORK PERFORMED BY GRUMMAN UNDER CONTRACT F33615-77-C-5169 SPONSORED BY
U.S.A.F. FLIGHT DYNAMICS LABORATORY

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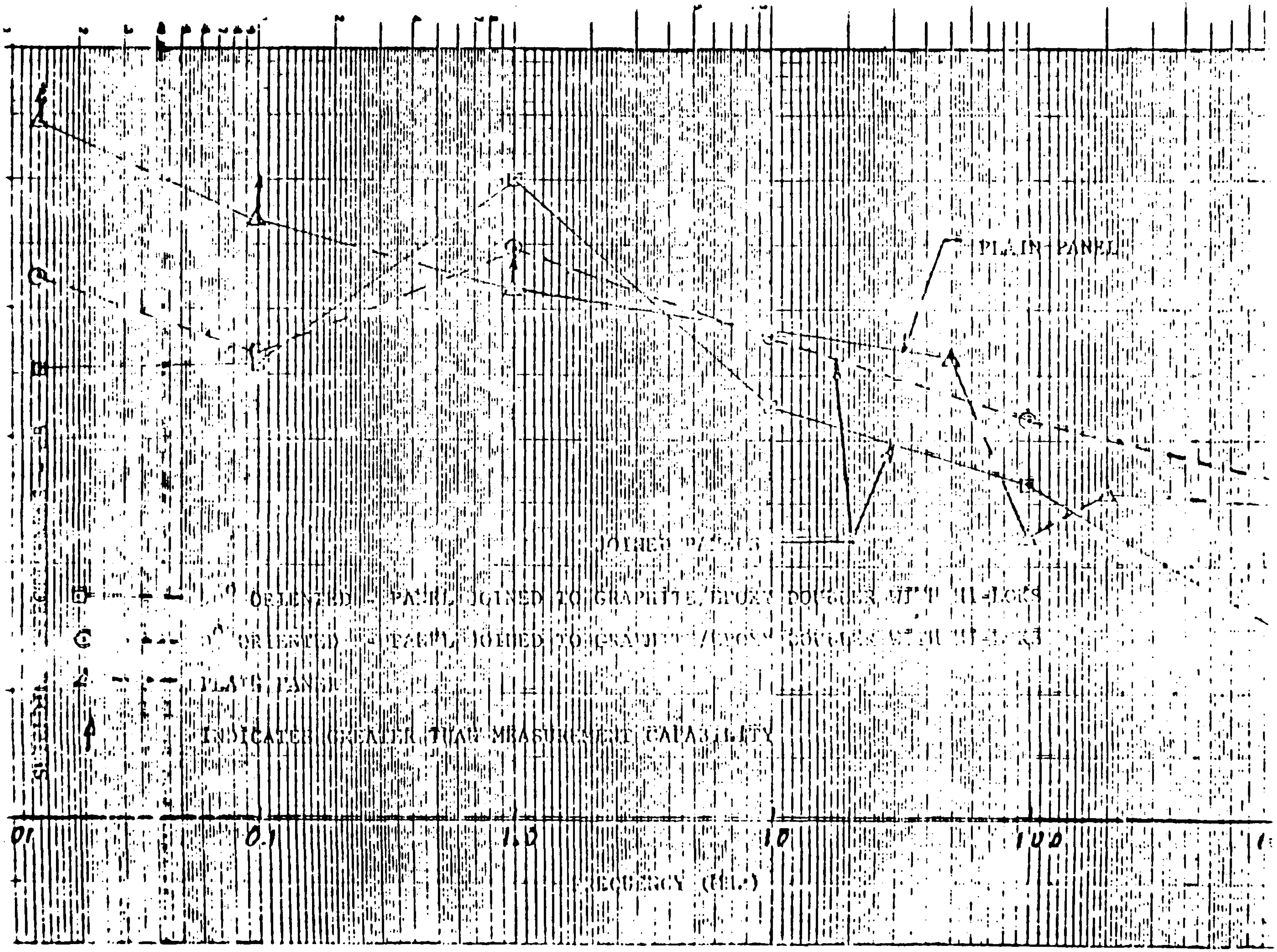
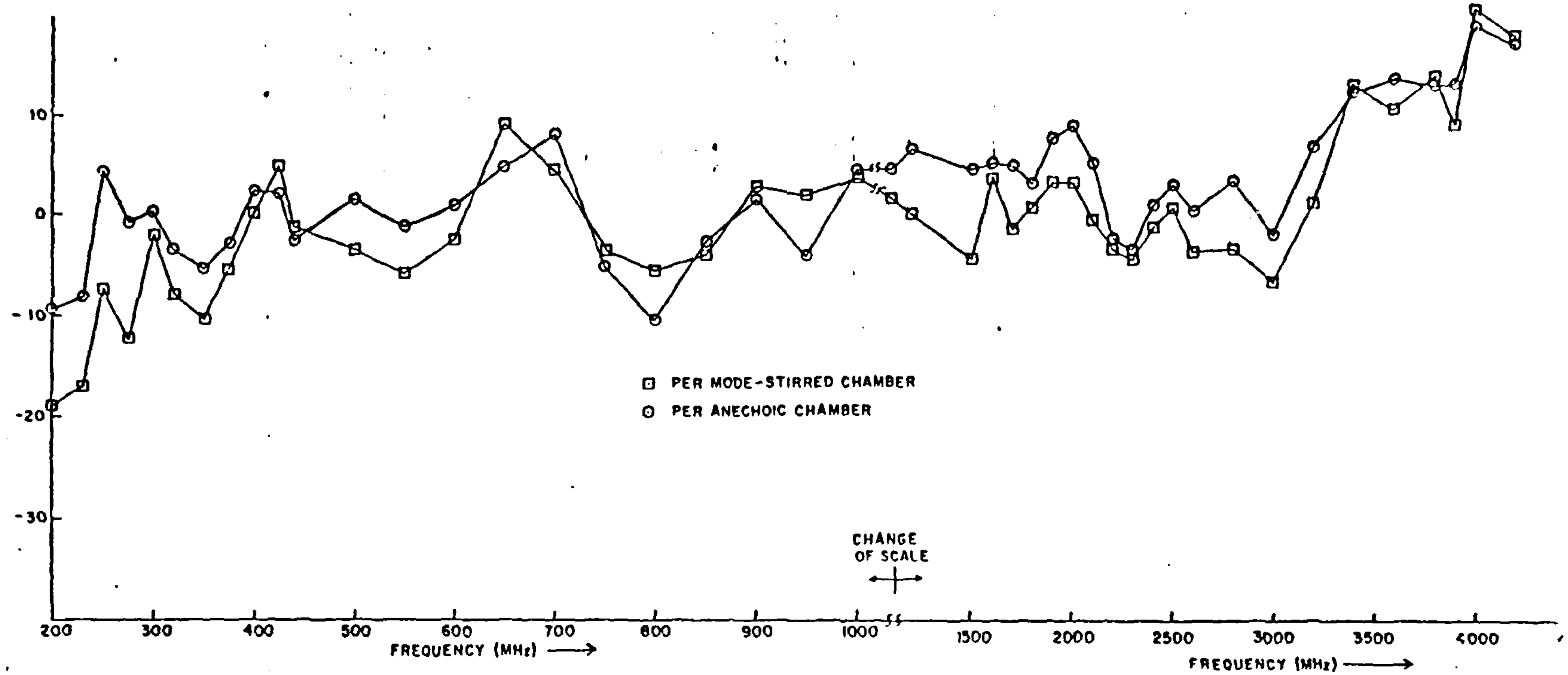

PLAIN PANEL
INDICATES GREATER THAN MEASUREMENT CAPABILITY
0.1
1.0
10
100

SYSTEM SUSCEPTIBILITY PROFILE



Joe Reardon
Naval Research Laboratory

NACM/TSCC Program Review
June 13-15, 1978
Paper C-11

Development of Electric?' Conductive
Graphite-Fiber Reinfo· : Composites

Joseph P. Rea. n
Code 6170, Naval Research Laboratory

The purpose of this new NAVAIR-sponsored program is to develop highly conductive graphite fiber suitable for incorporation into composites. It is expected that one or two plies of fiber of high electrical conductivity will suffice for providing greatly enhanced shielding of electronic equipment within a composite structure against electromagnetic interference (EMI) as well as improved protection against damage from lightening and accumulated electrostatic charge. NRL's first choice for this task is a highly graphitized pitch-base fiber developed by Union Carbide. The inherent high conductivity of this highly graphitized fiber can be further increased five- to tenfold by forming stable intercalation compounds. Conductivities about one-tenth that of aluminum have been achieved to date and further improvements are anticipated as new intercalants are tried. It is recognized, however, that the need for long-term chemical stability may preclude adoption of some of the electrically more favorable intercalants.

Intercalation of graphite fiber has to be done before prepregging. Consequently we elected to begin our work with woven fabric so we would be free to intercalate and prepreg the material in small lots, all in-house. Union Carbide has supplied us with the highly graphitized pitch fiber in a plain weave. The fiber has a density of 2.2 g/cc; the yarn tensile strength is about 400,000 psi and the Young's modulus is 110-120 million psi. Composites of epoxy and the intercalated fabric are visually indistinguishable from composites using the untreated fabric, and there has been no sign of escape of intercalant during cure. A series of composite plates is being fabricated that includes various proportions of the highly graphitized fabric (both untreated and with various intercalants) and T300 cloth. These plates are then being evaluated in terms of their electrical, mechanical, and chemical properties. The bulk of the EMI shielding evaluation will be carried out at NSWC-Dahlgren.

It is not our contention that better conductivity alone will solve the EMI and related problems. We do feel, however, that the hundred-fold increase in conductivity over that of current graphite/resin composites that we see as achievable will give the aeronautical engineer much more latitude in his design work.

Electromagnetic (EMI) Shielding

Shielding effectiveness = $R + A + I$

Absorptive Losses	Reflective Losses
$A \propto t\,(f\sigma\mu)^{1/2}$	$R \propto \log\left(\frac{\sigma}{f\mu}\right)$
Independent of impinging source field	For plane waves
Predominate in composites	Predominate in metals

t = thickness

f = frequency

σ = conductivity

μ = permeability

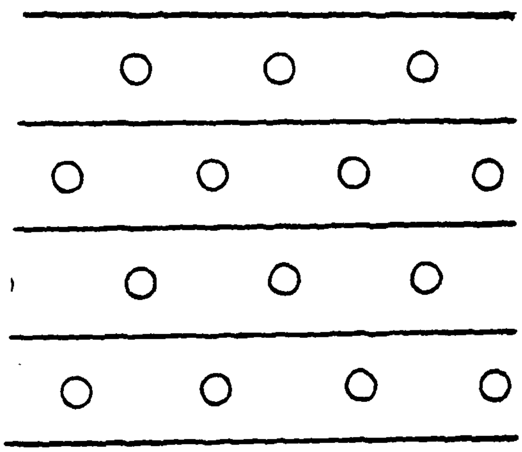
For electrostatic discharge (ESD):

$$\rho_{surface} \leq 10^9 \text{ ohm}.$$

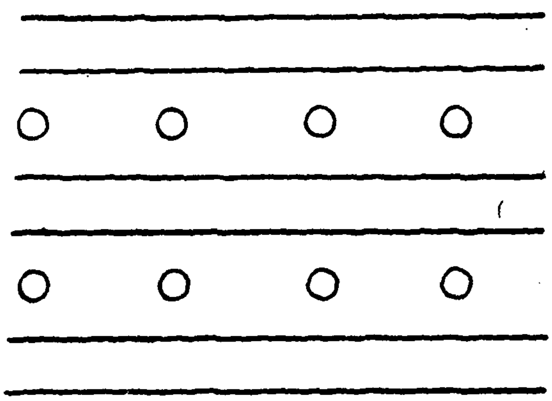
Intercalation

Graphite basal plane

Intercalant molecule



1st Stage



2nd Stage

etc.

PROPERTY	HGPF	T300
Diameter, μm	10	6-8
Tensile str., psi	~400000	361000
Modulus, psi	110-120 $\times 10^6$	32×10^6
Weave	Plain	Plain
Ends per inch	15 x 17	12½ x 12½
Areal weight,		
oz/yd^2	12.2	5.77
g/cm^2	0.041	0.019
Ply thickness in composite, mils	24.3	8.2

HGPF = Highly graphitized pitch fiber

T300 = Thornel 300 cloth, woven by HEXCEL.

NRL

Material	Volume Conductivity, as $10^4 (\Omega\,cm)^{-1}$
Copper	60
Aluminum	38
Aluminum alloys	16-33
Stainless steel 304	1.7
U.C. TP4101 (SbF_5)	4.6 (predicted)
" " (ICl)	3.2
" " (as rec'd)	0.58
Celanese GY70	0.10
Hercules AS	0.03

NRL

Epoxy Resin System — for fabrication of composites with conductive graphite fiber.

Shell's EPON 828
HHPA

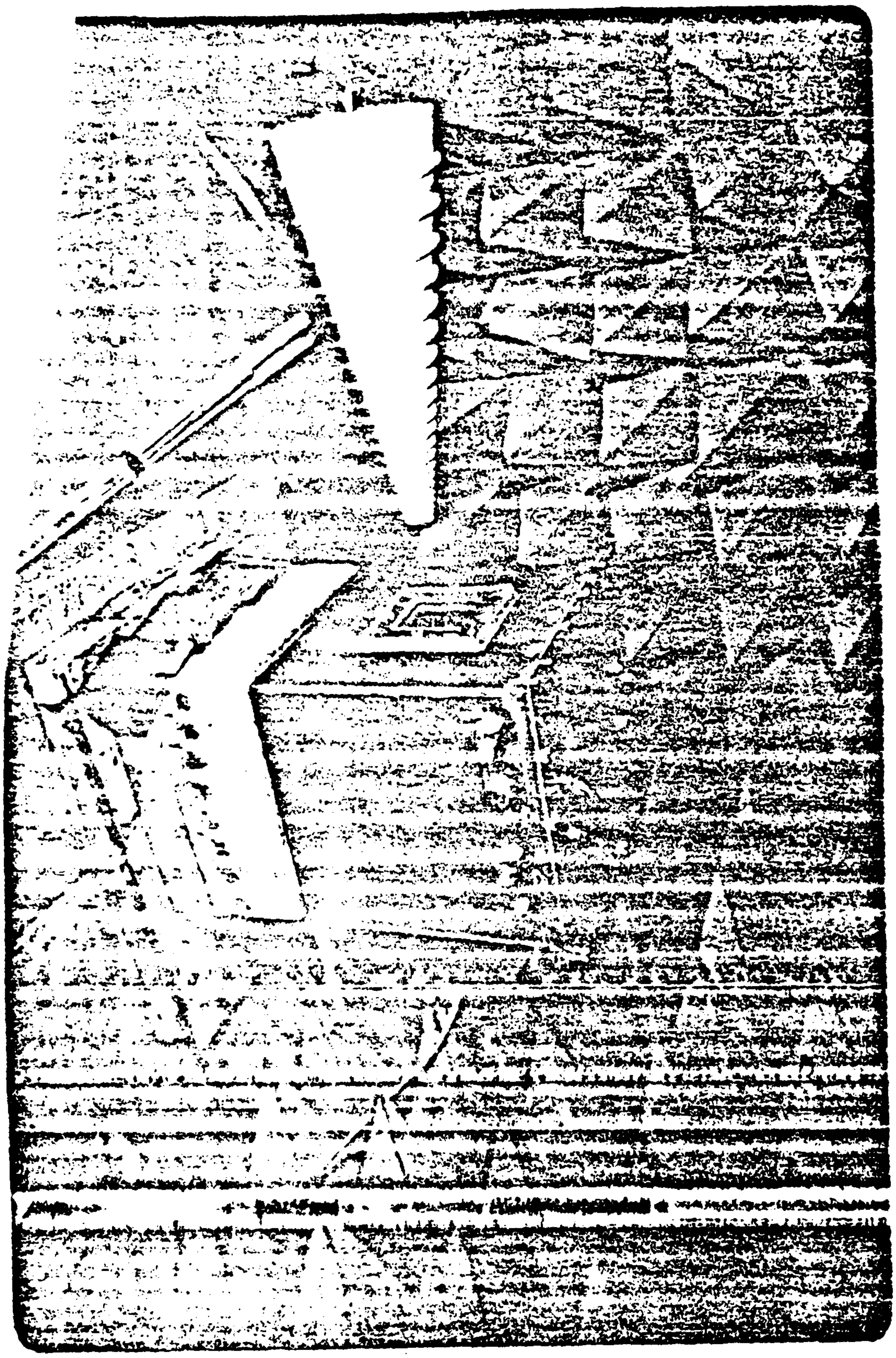
Epoxide/Anhydride = 1.0/0.45

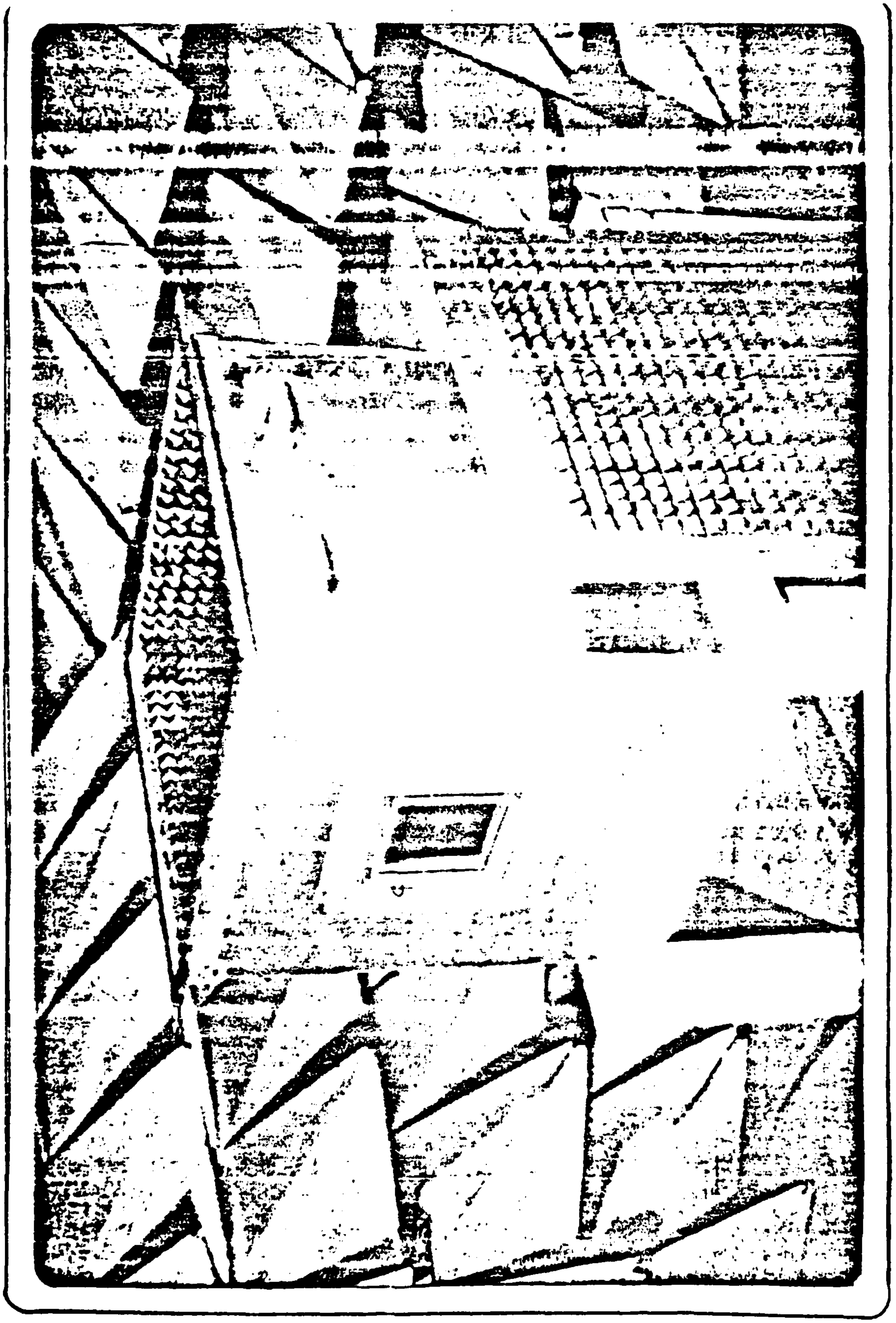
+ 0.2 % by wt. dimethylbenylamine as catalyst

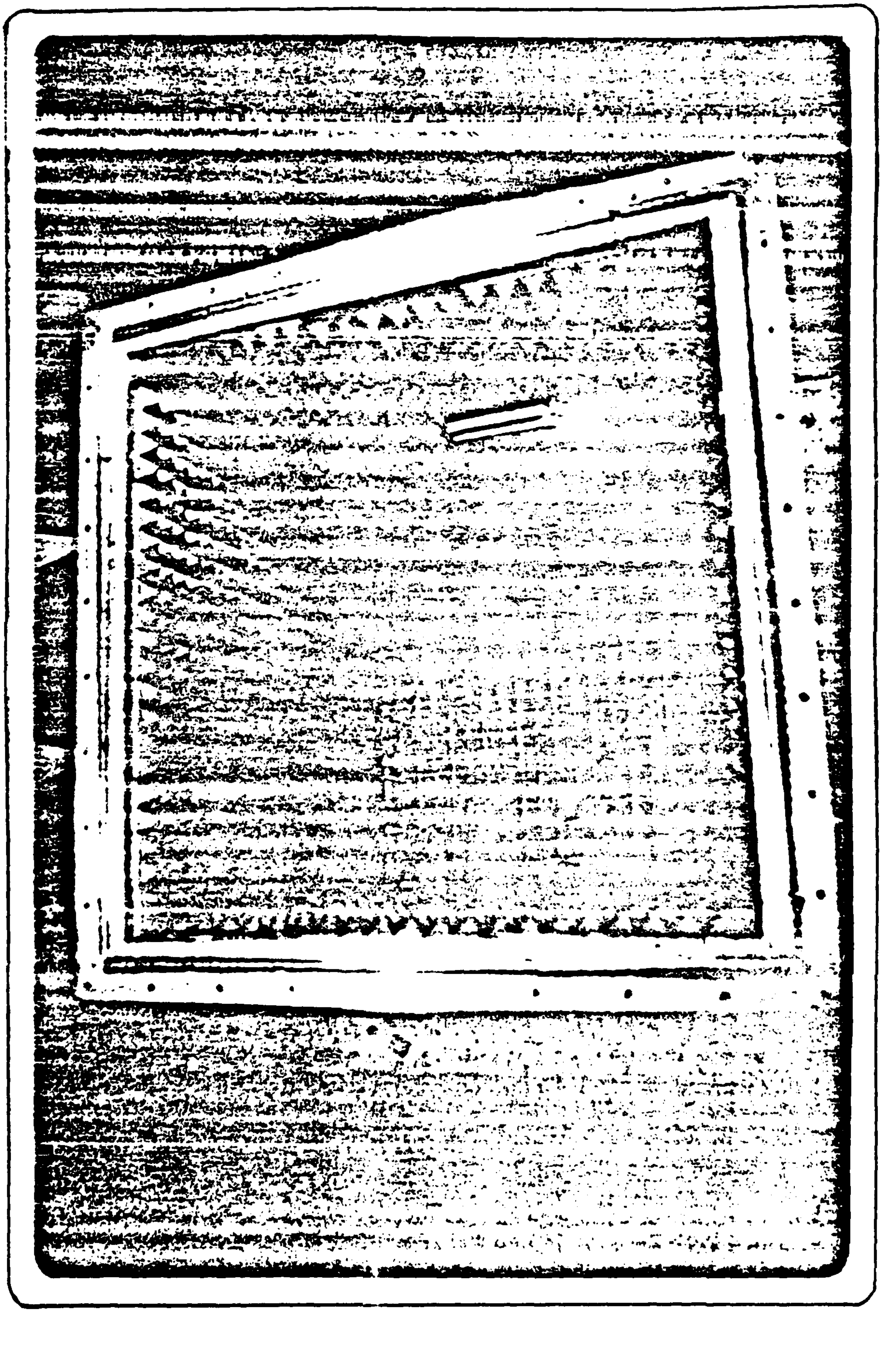
Cure: Up to 150°C (302°F) at 100 psi.

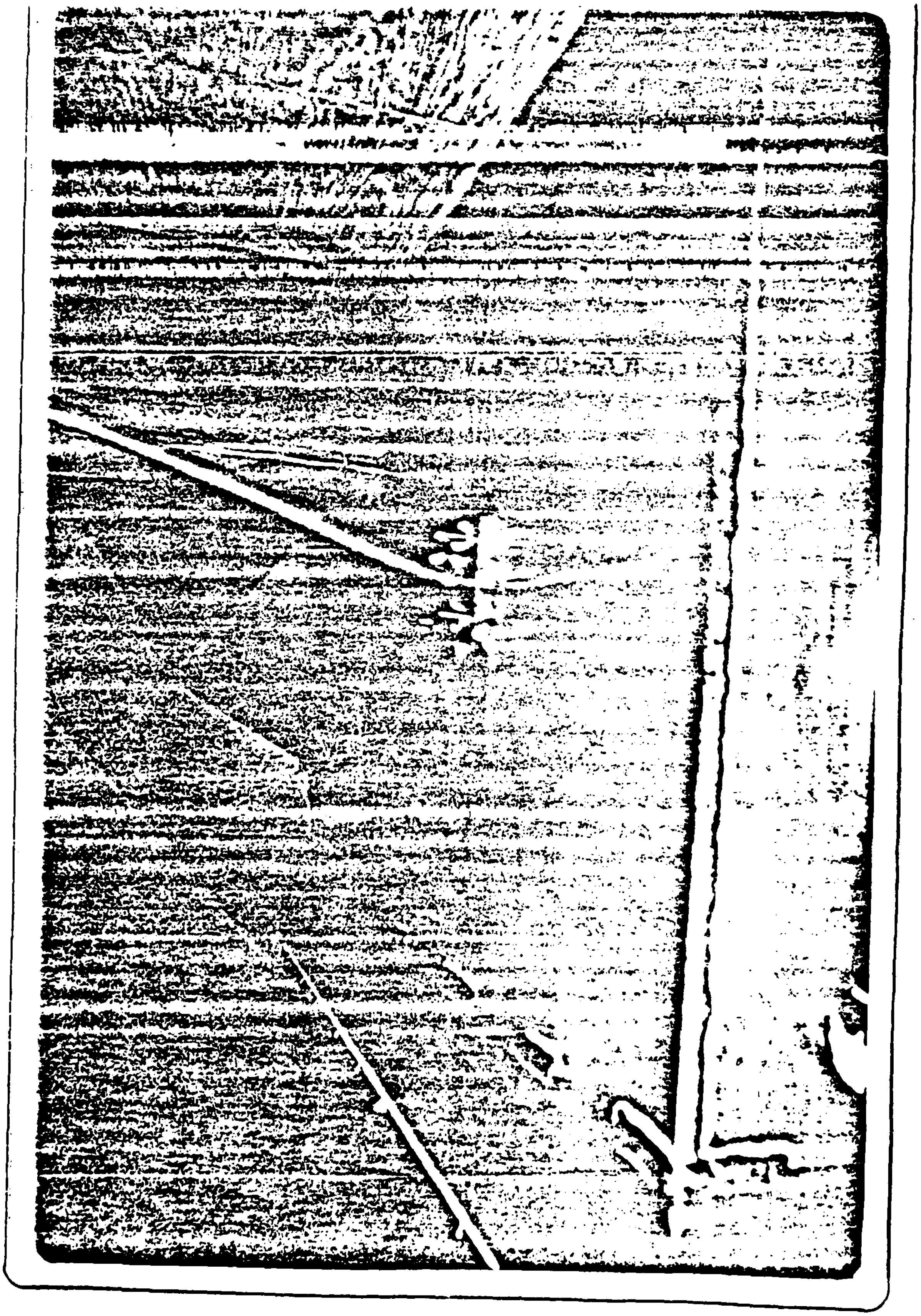
NRL

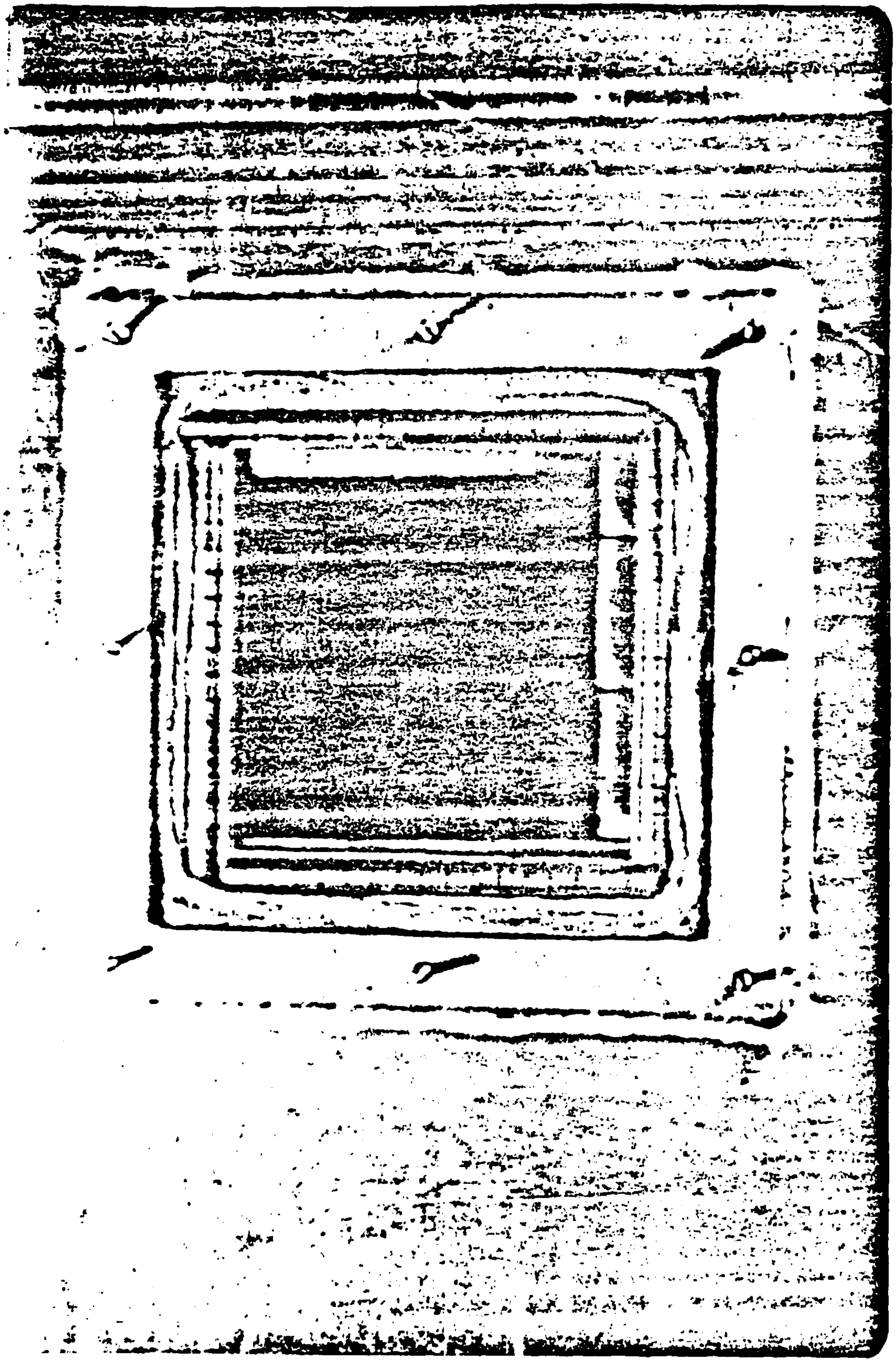
Ernest Donaldson
Georgia Institute of Technology

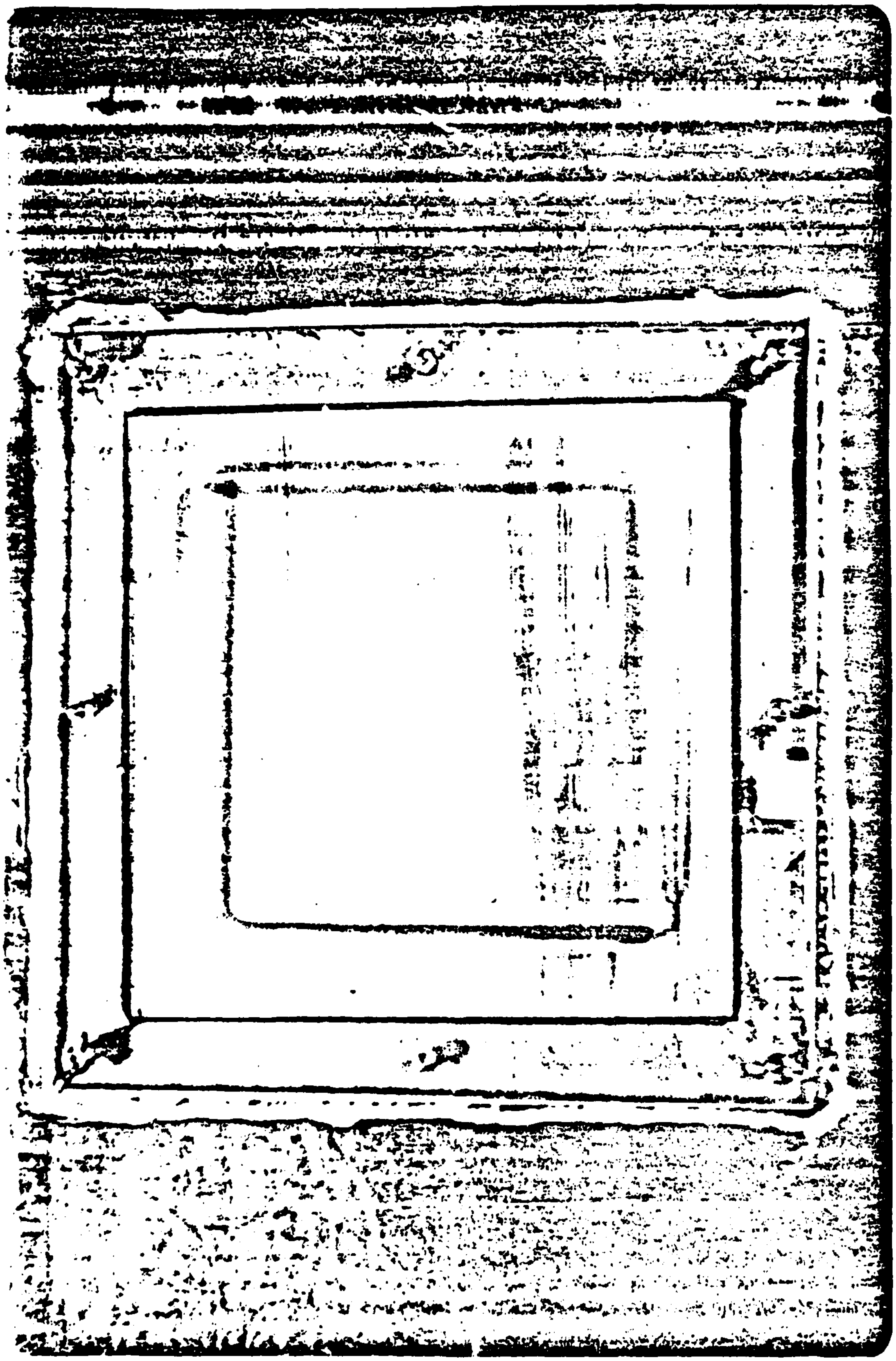


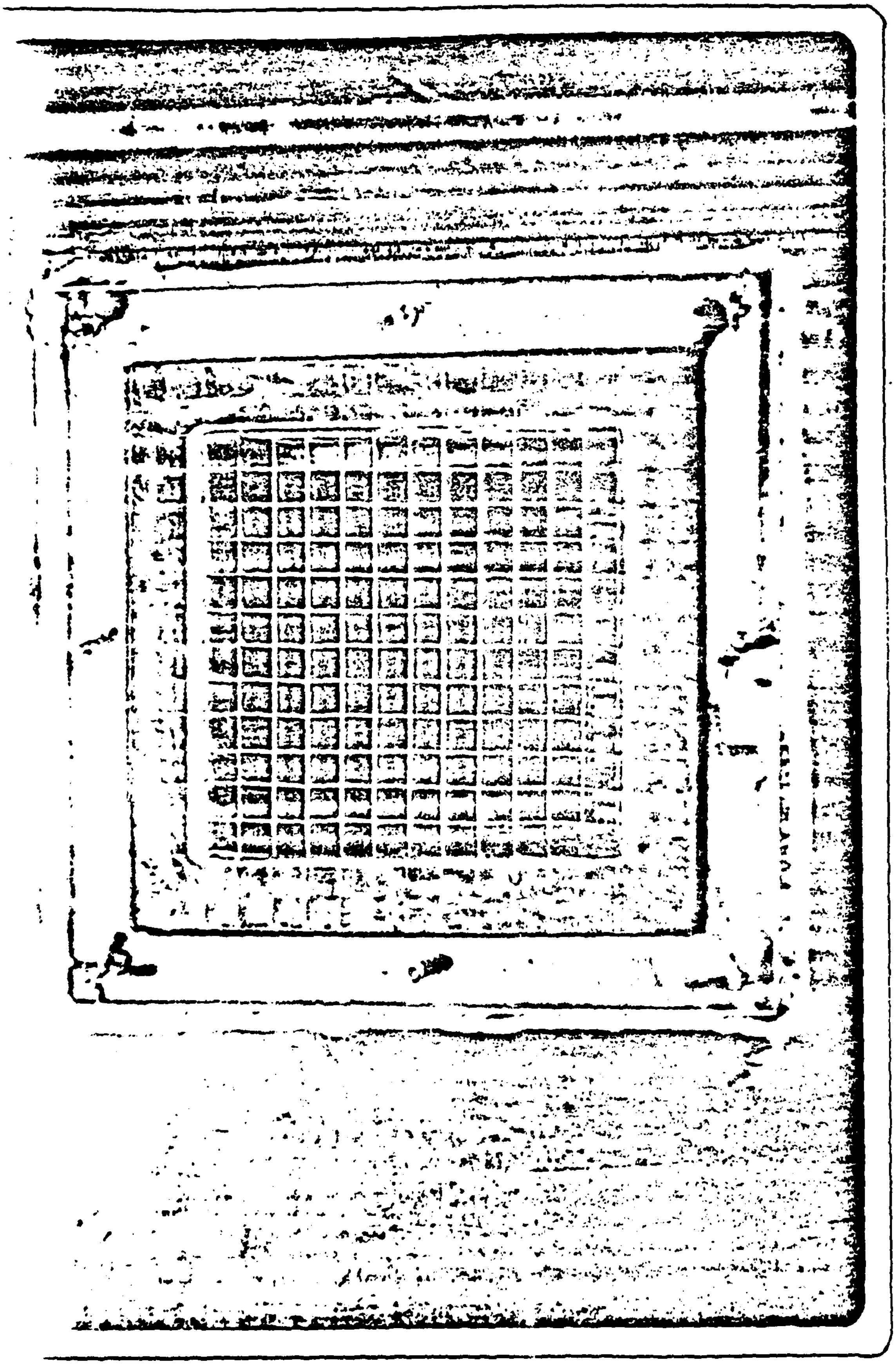


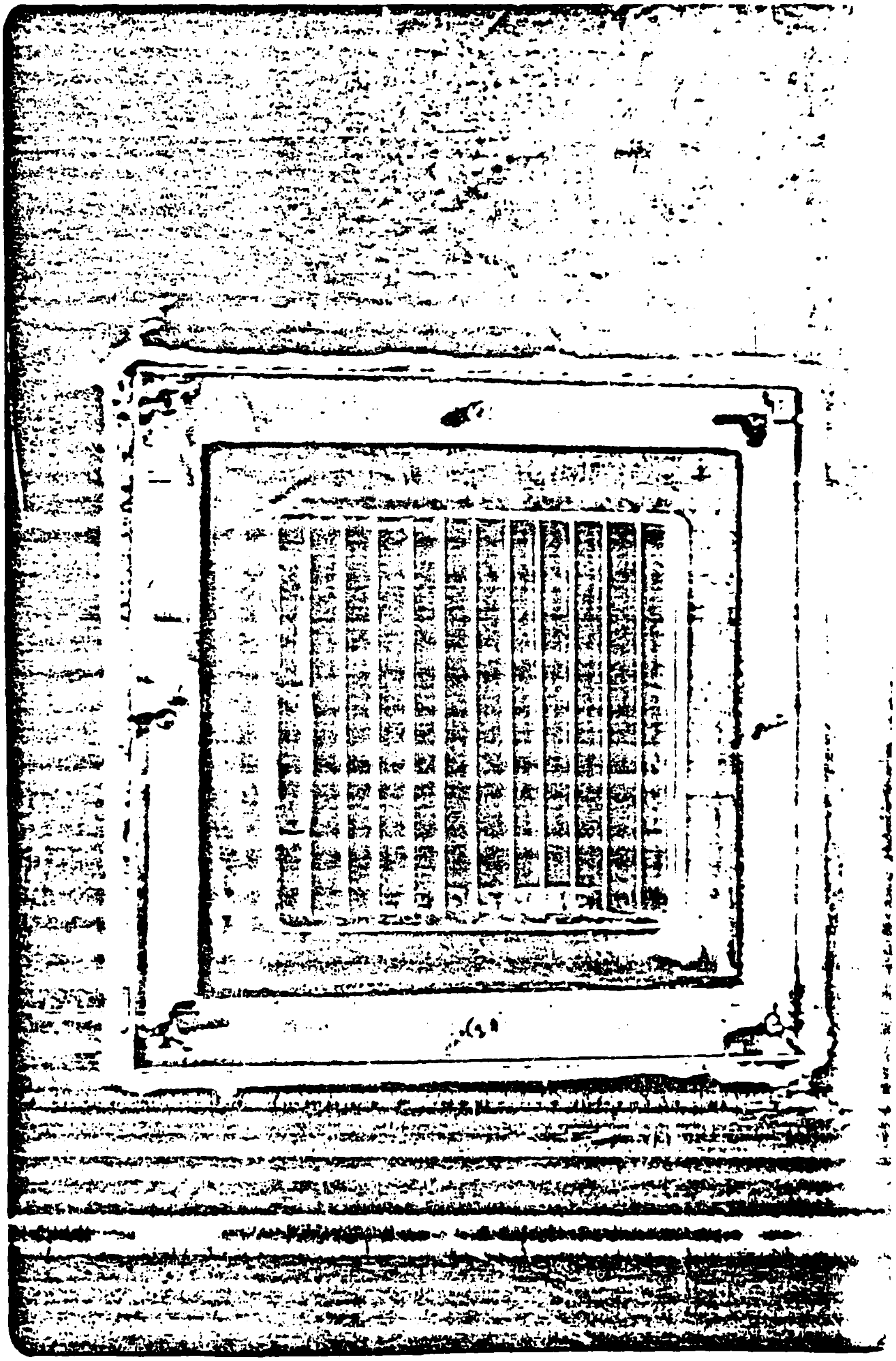


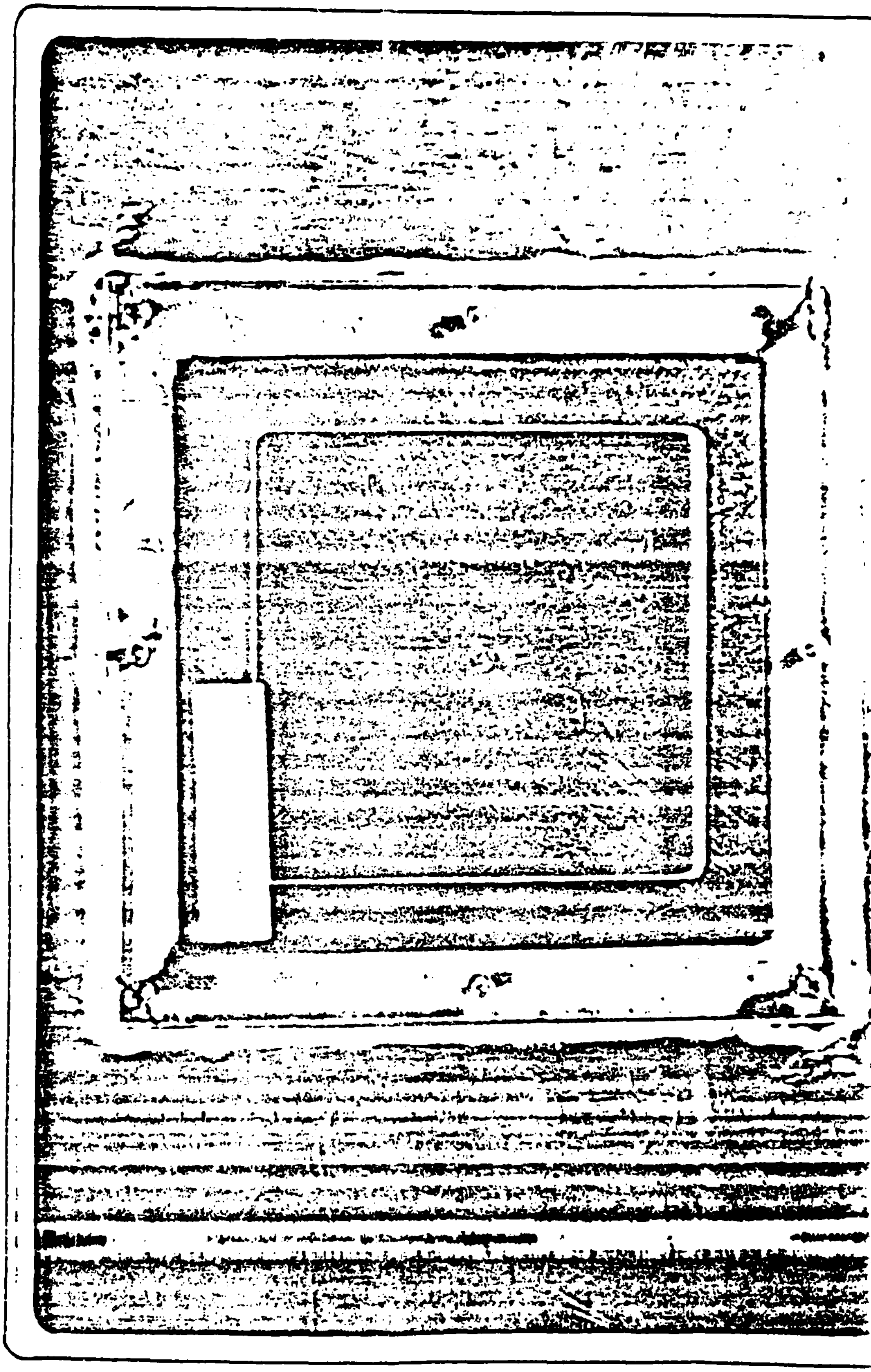


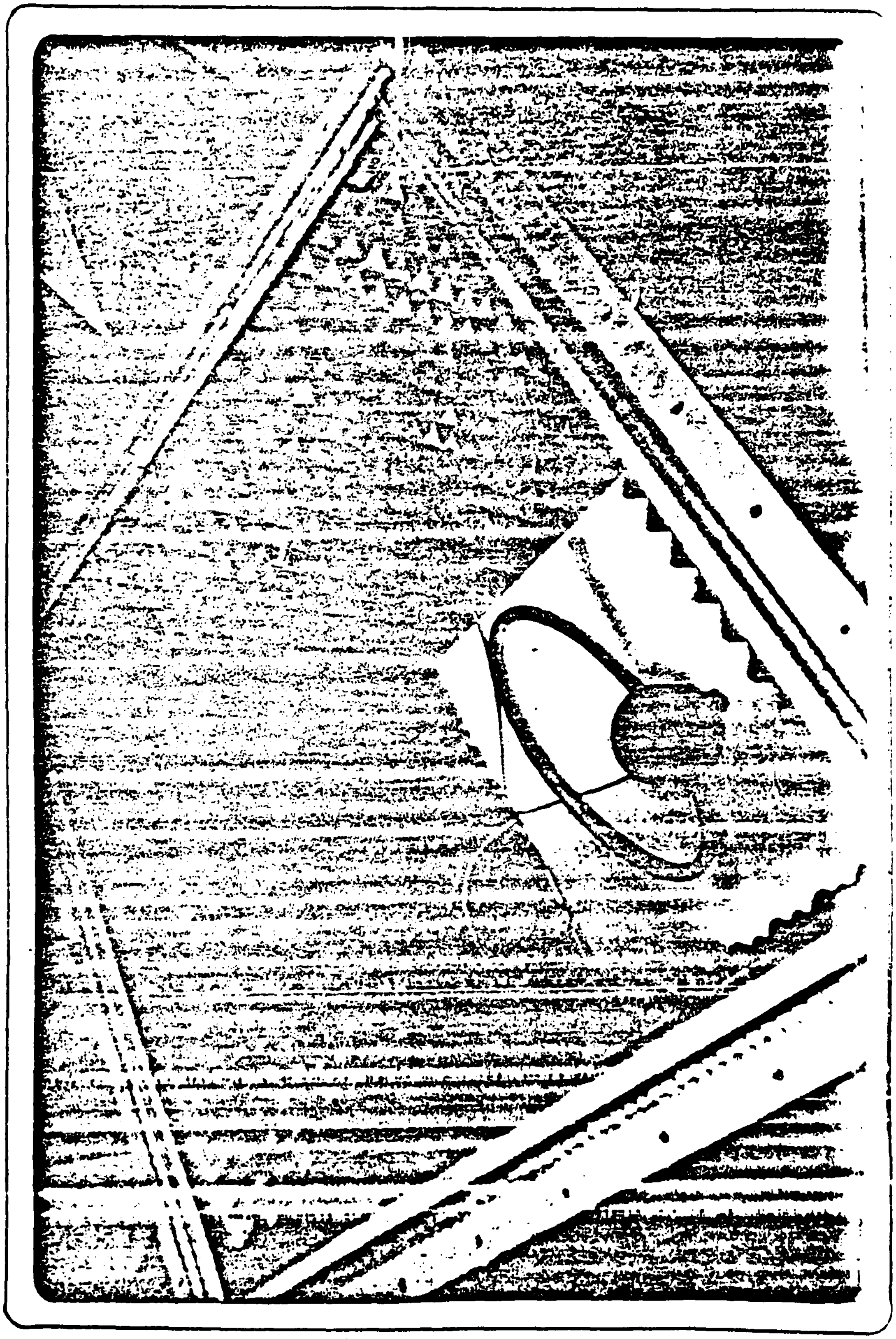


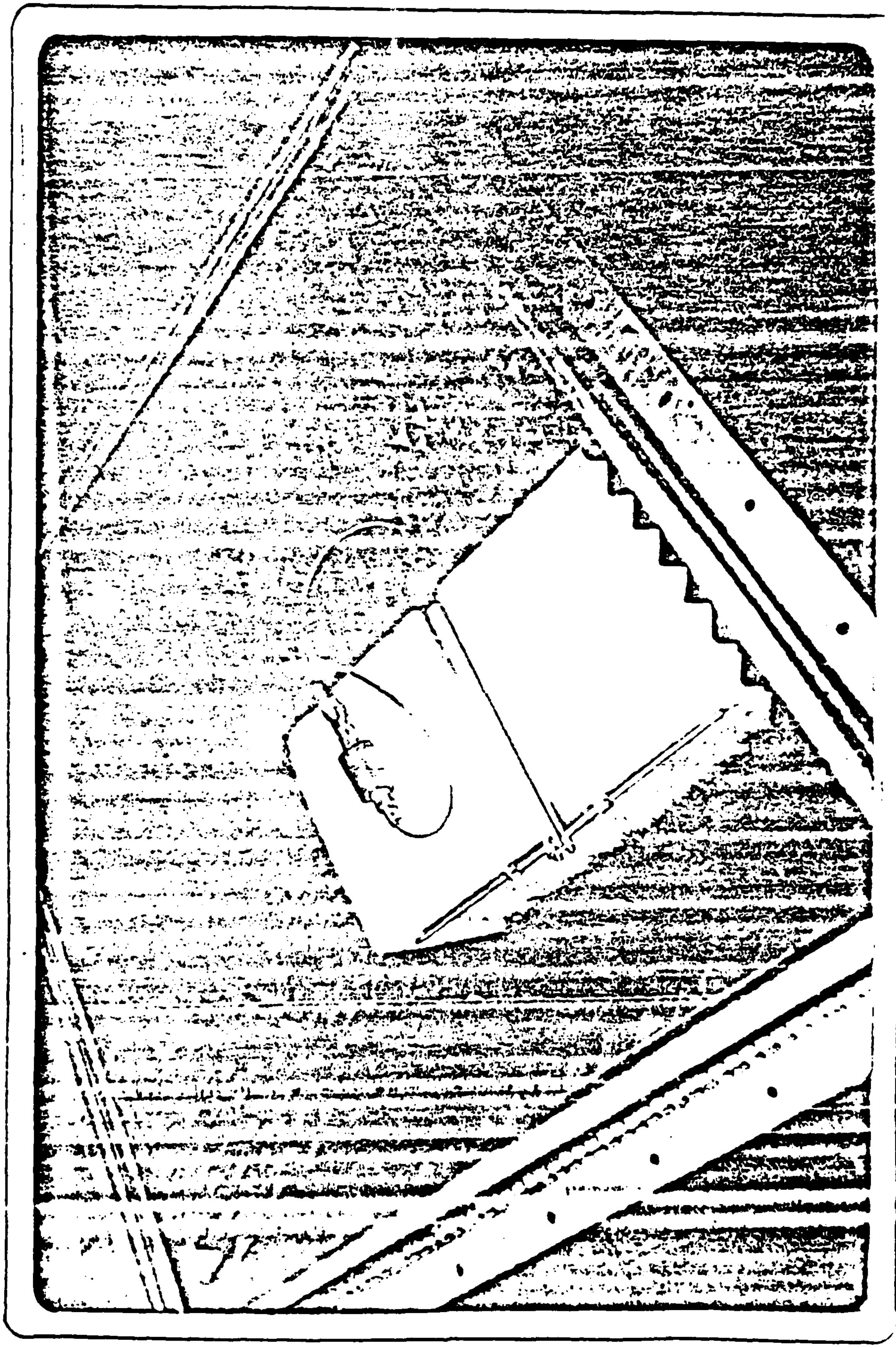


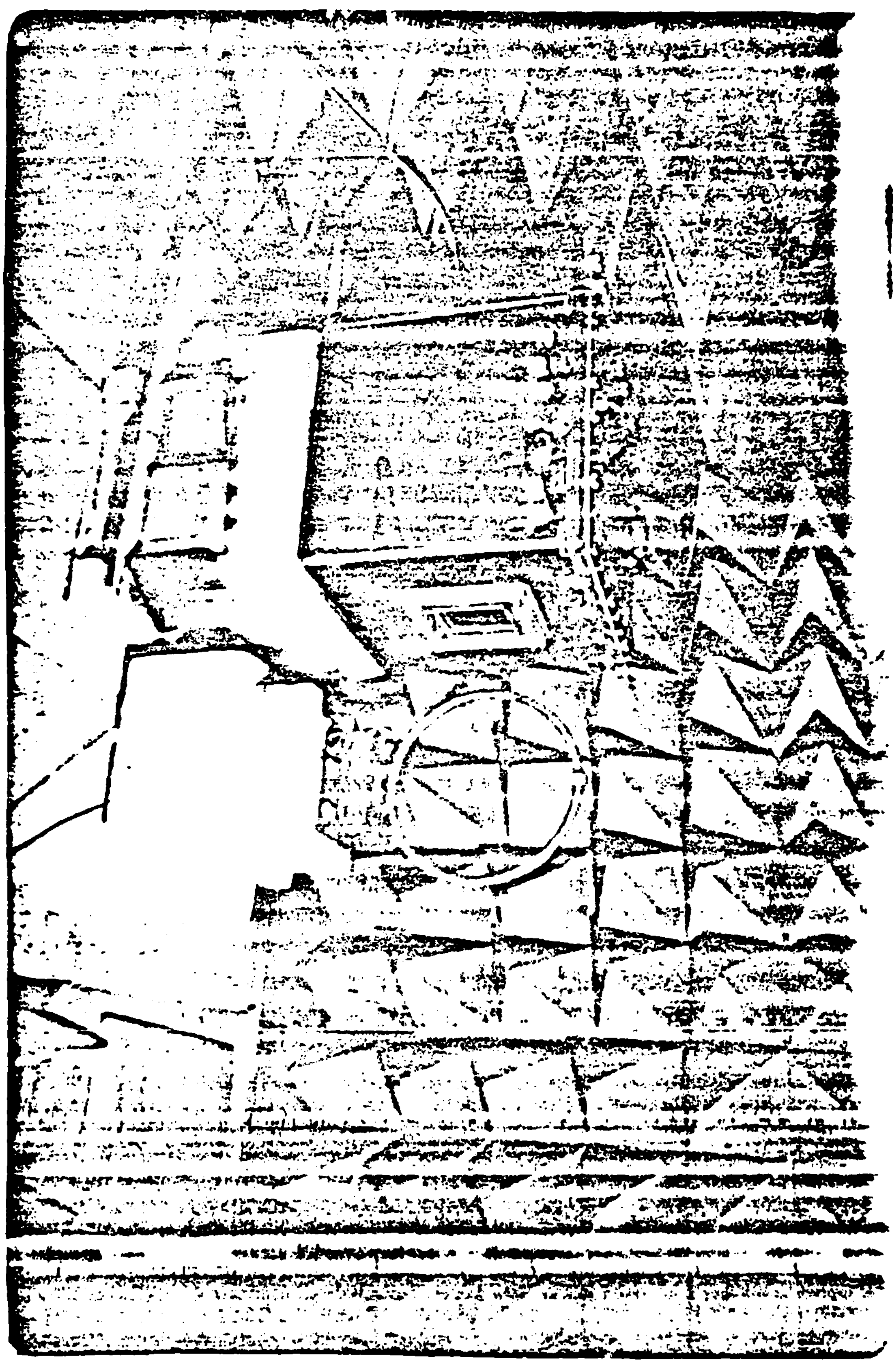


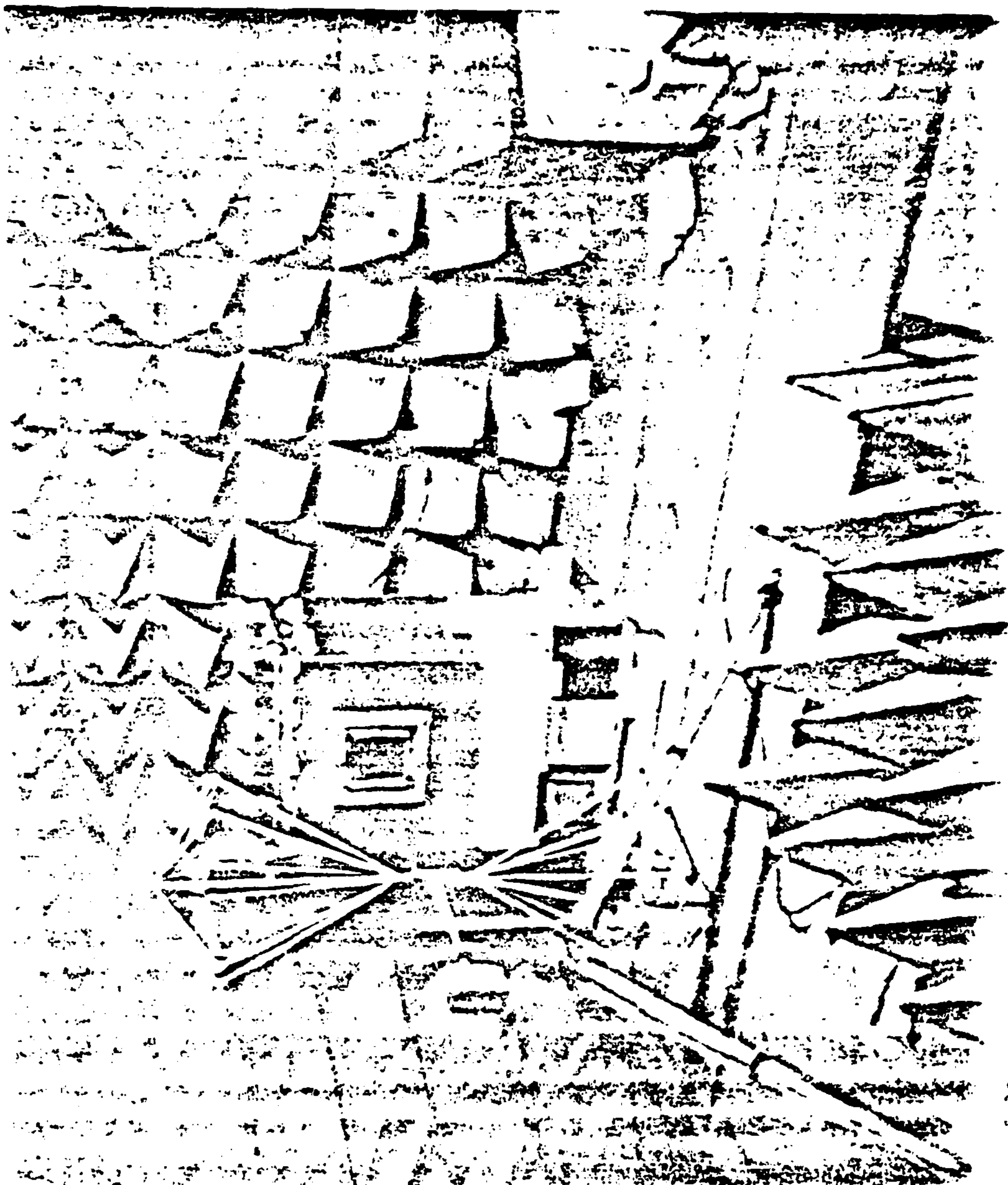












Dr. Roy Stratton

Rome Air Development Center

View Graphs Were not Available

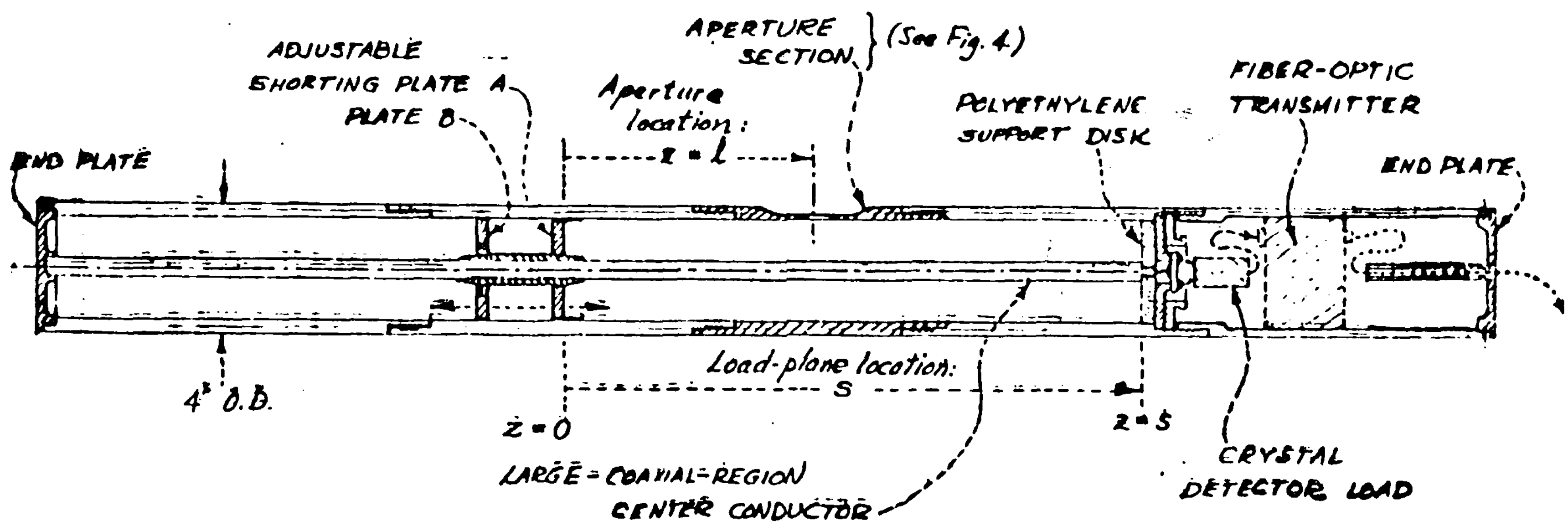


Figure 3. Sectional View of First Experimental Model

Dr. S. S. Tompkins

NASA Langley Research Center

Alternate Composite Materials to Minimize the Possible Carbon Fiber Electrical Hazard

ALTERNATE COMPOSITE MATERIALS TO MINIMIZE

THE POSSIBLE CARBON FIBER ELECTRICAL HAZARD

DR. S. S. TOMPKINS
MATERIALS DIVISION
NASA LANGLEY RESEARCH CENTER
HAMPTON, VA 23665

ALTERNATE COMPOSITE MATERIALS

OBJECTIVE: PROVIDE FIBERS, RESINS AND HYBRID COMPOSITES WHICH REDUCE THE ELECTRICAL HAZARD IDENTIFIED FOR CARBON FIBERS WHILE RETAINING OR IMPROVING THE STRUCTURAL PROPERTIES OF POLYMERIC RESIN MATRIX COMPOSITES FOR AEROSPACE APPLICATIONS.

ALTERNATE COMPOSITE MATERIALS

APPROACH

- FIBER MODIFICATIONS AND COATINGS
  - INTERCALATION OF GRAPHITE FIBERS
  - GLASS, CARBIDE, ORGANIC COATINGS
- IMPROVED MATRIX MATERIALS
  - IMPROVED CHAR FORMING
  - FIRE-RESISTANT, FLAME RETARDANT
- ALTER DISSEMINATION CHARACTERISTICS
  - INCREASE "CLUMPING" - HYBRIDS, WEAVES
  - INCREASE FALL VELOCITY - DIAMETER
- COMBUSTIBLE FIBERS
- NEW FIBERS
  - ORGANIC
  - BORON NITRIDE

ALTERNATE COMPOSITE MATERIALS

APPROACH	NASA CENTER
● FIBER MODIFICATIONS AND COATINGS	
INTERCALATION OF GRAPHITE FIBERS	LANGLEY
GLASS, CARBIDE, ORGANIC COATINGS	
● IMPROVED MATRIX MATERIALS	LEWIS
IMPROVED CHAR FORMING	AMES
FIBER-RESISTANT, FLAME RETARDANT	LANGLEY
● ALTER DISSEMINATION CHARACTERISTICS	LEWIS
INCREASE "CLUMPING" - HYBRIDS, WEAVES	LANGLEY
INCREASE FALL VELOCITY - DIAMETER	
● COMBUSTIBLE FIBERS	LANGLEY
● NEW FIBERS	LEWIS
ORGANIC	LANGLEY
BORON NITRIDE	

LARC PROGRAM OVERVIEW

I. FIBER COATINGS
   - A. INORGANIC
   - B. ORGANIC
   - C. COATING TECHNIQUES

II. GRAPHITE FIBER
   - A. NEW FABRICATION PROCESSES
   - B. MODIFY EXISTING FIBER

III. NONGRAPHITE FIBERS

IV. HYBRIDS
   - A. LAMINATES
   - B. MATRICES

V. ALTERNATE MATRIX COMPOSITES

FIBER MODIFICATIONS
RPI

APPROACHES

- ALTER CRYSTALLINE STRUCTURE THROUGH PROCESSING
- EXPLORE C-B-N SYSTEM
- INVESTIGATE BN COATING

STATUS

- APPARATUS TO MEASURE CONDUCTIVITY AND STRENGTH BEING CONSTRUCTED
- PRELIMINARY RESULTS SHOW PITCH FIBERS HAVING $R = 10^7 - 10^8$ OHM/CM

HIGH RESISTIVITY INTERCALATED GRAPHITE FIBERS

OBJECTIVE: DETERMINE THE FEASIBILITY OF SIGNIFICANTLY INCREASING THE ELECTRICAL RESISTIVITY OF GRAPHITE FIBERS WITHOUT DEGRADING MECHANICAL PROPERTIES

APPROACH: TREAT FIBERS WITH STRONG ACIDS TO INTERCALATE WITH OXYGEN, FLUORINE, NITROGEN, SULFUR, OR OTHERS

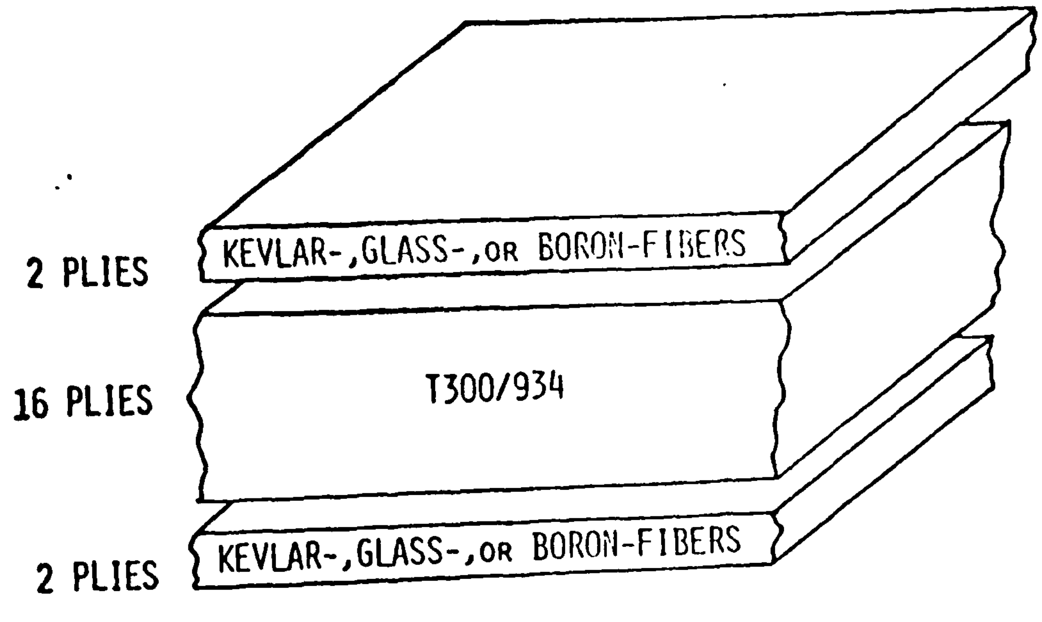
STATUS

- WORK IS UNDERWAY AT THE UNIVERSITY OF PA AND FT. BELVOIR
- PRESENT EMPHASIS IS ON GRAPHITE-OXYGEN SYSTEM
- RESISTIVITY OF GY-70 AND TYPE P FIBERS HAS BEEN INCREASED BY 9000 X
- MECHANICAL PROPERTY TESTS ARE BEING SET UP
- SAMPLES ARE BEING PREPARED FOR CHEMICAL ANALYSIS

NEAR TERM ACTIVITIES:

- EXPERIMENTS WITH T-300, AS, AND CELION FIBERS
- THERMAL STABILITY TESTS

7.6 x 7.6 CM x 20 PLIES, 934 EPOXY RESIN FABRICATED ...



SUMMARY OF STATUS

- OBTAINED A FACTOR OF 10^6 INCREASE IN RESISTANCE OF FIBER WITH SiO_2 COATING
- FIBER RESISTIVITY INCREASED BY 9000X THROUGH INTERCALATION WITH OXYGEN
- HYBRIDS OF GLASS AND BORON FILAMENTS SIGNIFICANTLY REDUCE AMOUNT OF GRAPHITE FIBERS RELEASED ON IMPACT OF BURNED SPECIMENS
- PRELIMINARY RESULTS SHOW PITCH FIBERS HAVING $R = 10^7 - 10^8$ OHM/CM

REFERENCES

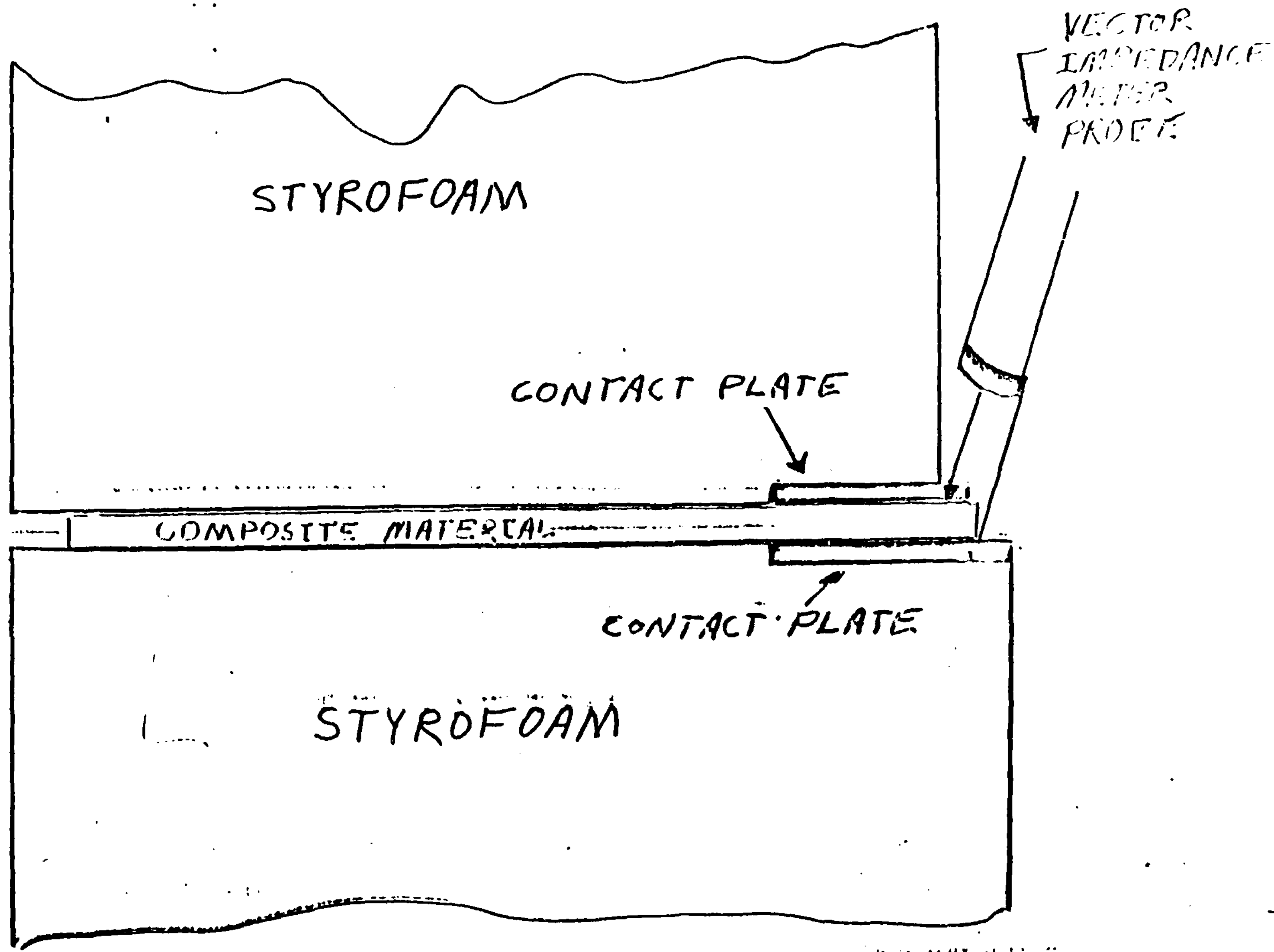
1. "A REPORT OF OBSERVED EFFECTS ON ELECTRICAL SYSTEMS OF AIRBORNE CARBON/GRAPHITE FIBERS." NASA TM 78652, JAN 1978.
2. "CARBON FIBER STUDY" COMPILED BY INTERGOVERNMENTAL COMMITTEE NASA TM 78718, MAY 1978.
3. "MODIFIED COMPOSITE MATERIALS WORKSHOP" COMPILED BY DENNIS L. DICUS, NASA TM 78761, JULY 1978.
4. "PRELIMINARY BURN AND IMPACT TESTS OF HYBRID POLYMERIC COMPOSITES" BY S.S. TOMPKINS AND W.D. BREWER, NASA TM 78762, JULY 1978.

D. Swink
NSWC/Dahlgren

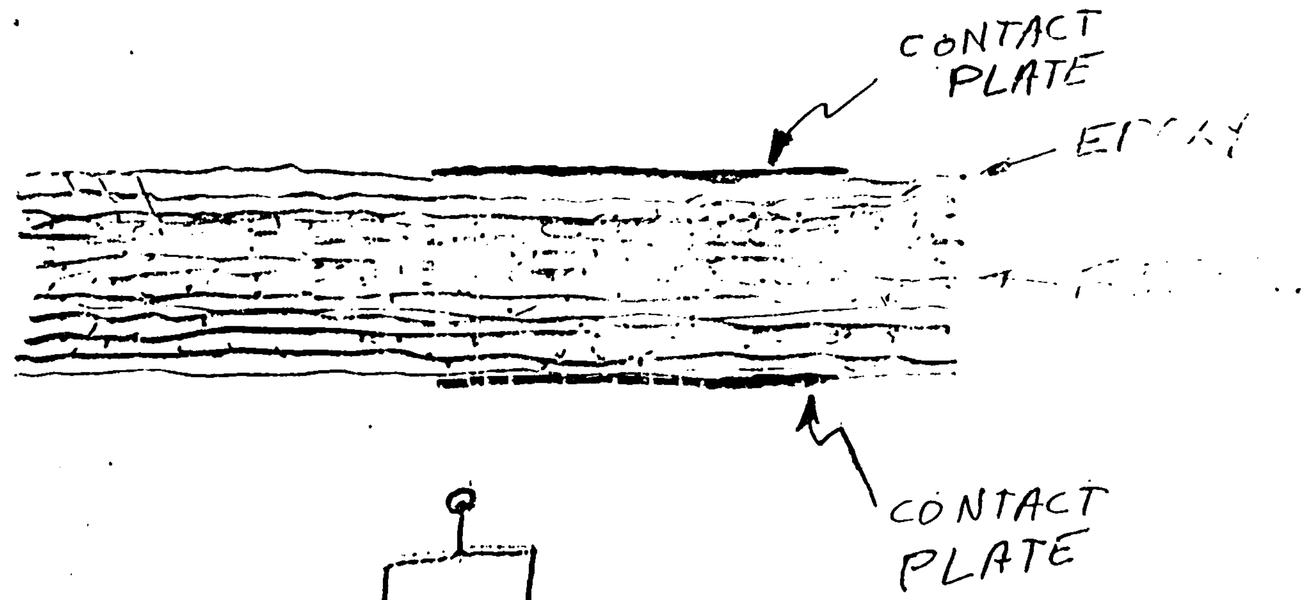
MEASUREMENT TECHNIQUES

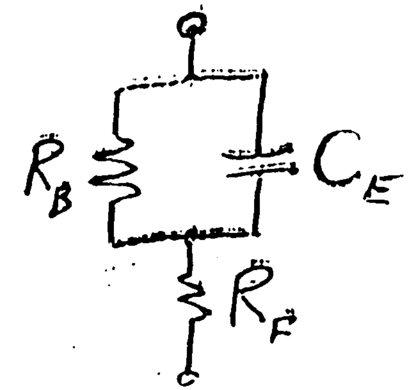
TYPE	YIELDS
MODE-STIRRED CHAMBER	SHIELDING EFFECTIVENESS
CONTACT IMPEDANCE	MATERIAL / JOINT MODEL

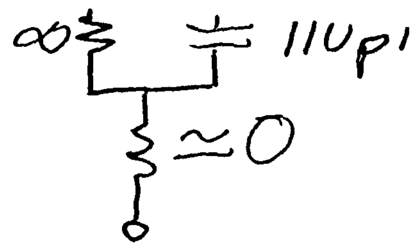
CONTACT IMPEDANCE MEASUREMENT



LOW FREQUENCY MODEL

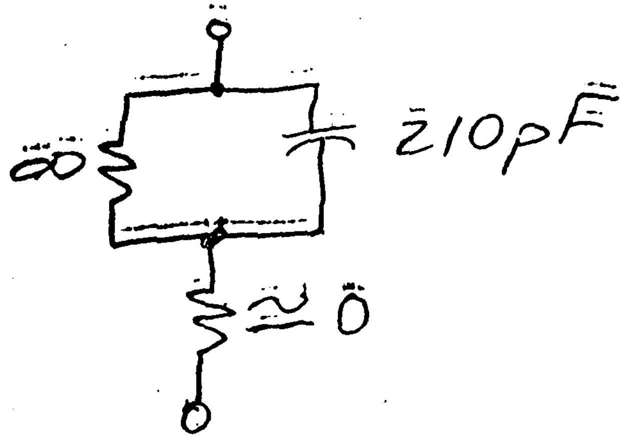






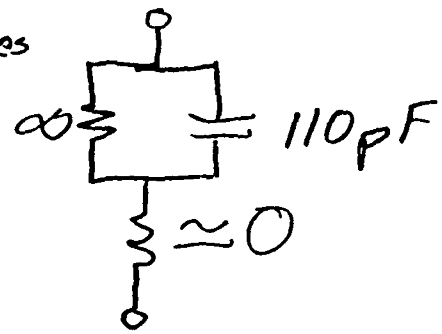
(assuming

1.4" contact plates



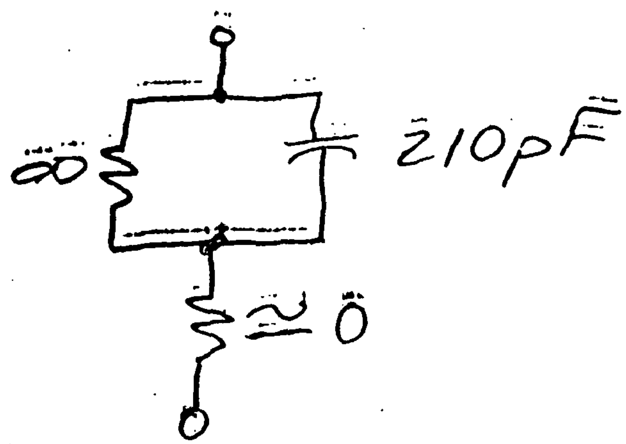
T-300, 1/4" Thick

1" contact plates



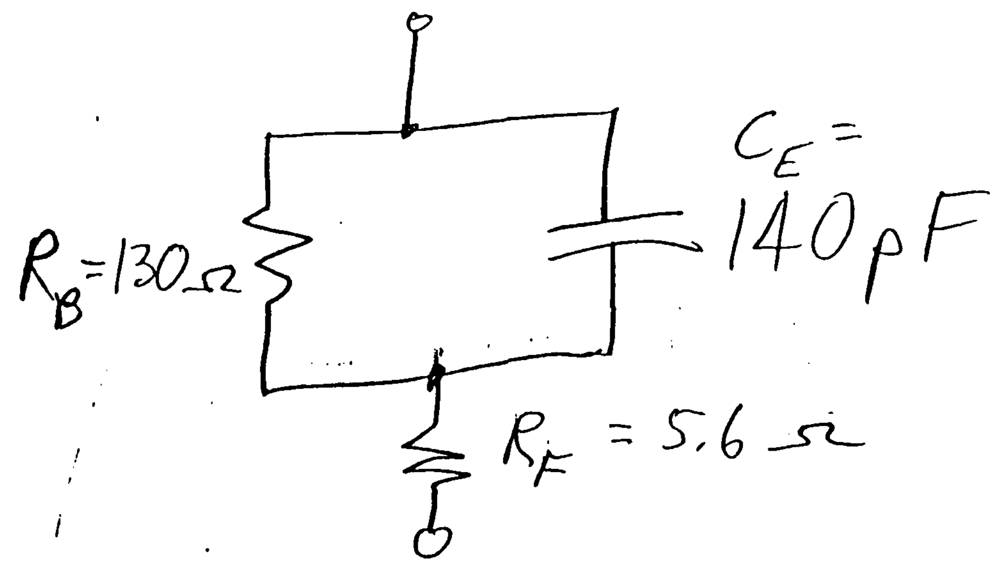
$t \simeq 6$ mils
(assuming $\epsilon_r \simeq 3$)

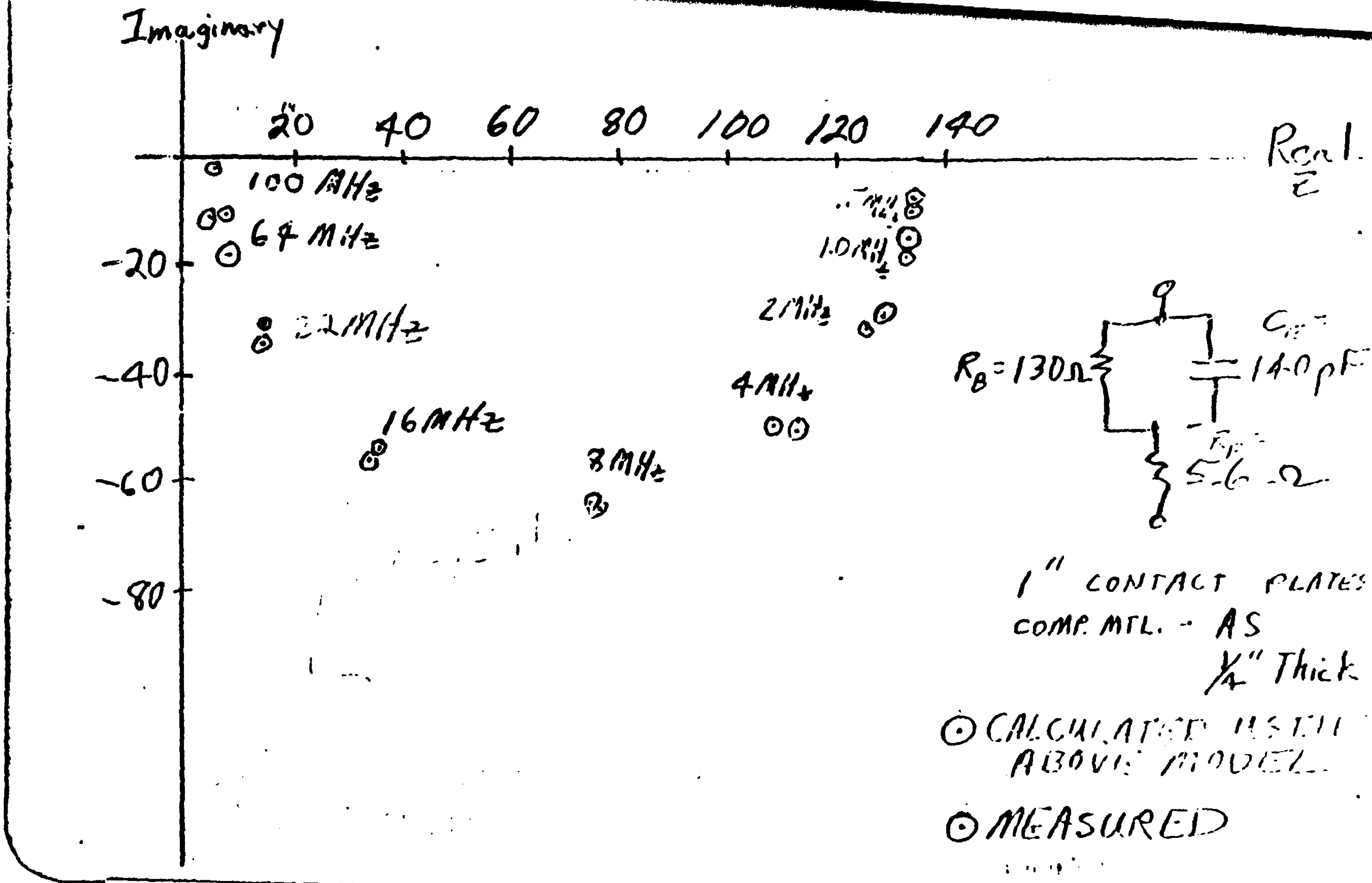
1.4" contact plates



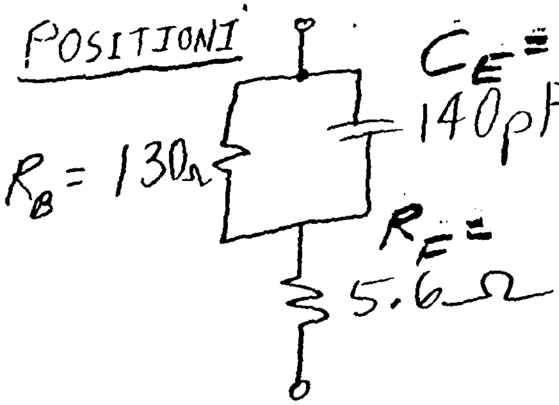
AS, 1/4" Thick

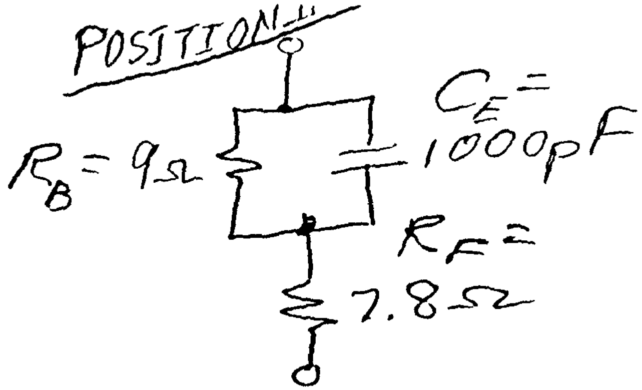
1" contact plates



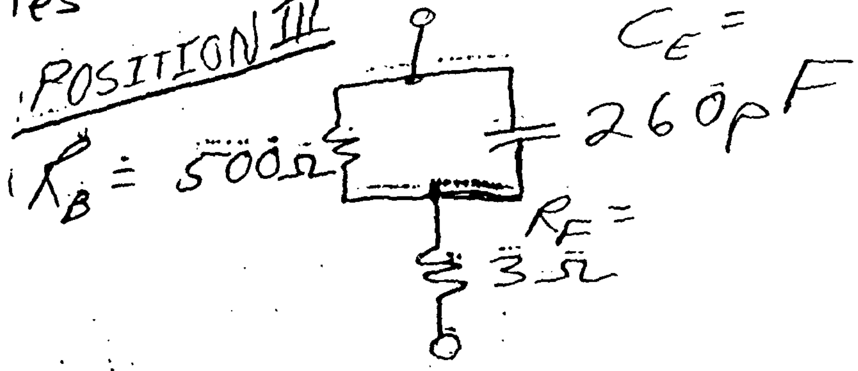


Imaginary
20
40
60
80
100
120
140
Real
-20
-40
-60
-80
100 MHz
64 MHz
16 MHz
8 MHz
4 MHz
2 MHz
1.0 MHz
$R_B = 130\Omega$
14.0 pF
5.6 Ω
1" CONTACT PLATES
COMP. MTL. - AS
1/4" Thick
CALCULATED USING ABOVE MODEL
MEASURED


POSITION I
$R_B = 130\Omega$
$C_E = 140pF$
$R_F = 5.6\Omega$


POSITION II
$R_B = 9\Omega$
$C_E = 1000pF$
$R_F = 7.8\Omega$

1.4" Plates


POSITION III
$R_B = 500\Omega$
$C_E = 260pF$
$R_F = 3\Omega$

Rom Prehoda

NSWC/Dahlgren

PURPOSE

Develop Information, Methods or Techniques that can be used by,

1. ELECTRONIC SYSTEMS DESIGNERS
2. EVALUATION ENGINEERS

[illegible] coupling program

APPROACH

[illegible] ANALYTICAL & EXPERIMENTAL METHODS TO:

- DEVELOP EFFECTIVE TEST TECHNIQUES
- DEVELOP ANALYTICAL PREDICTION TECHNIQUES
- DETERMINE THE VALIDITY BY COMPARING RESULTS WITH ANECHOIC CHAMBER MEASUREMENTS

ACCEPTABILITY CRITERIA

PROVIDE VALID INFORMATION

PROVIDE TIMELY IMPACT

GENERATE USER CONFIDENCE

APPLY TO 100 KHz - 12 GHz FREQUENCY RANGE

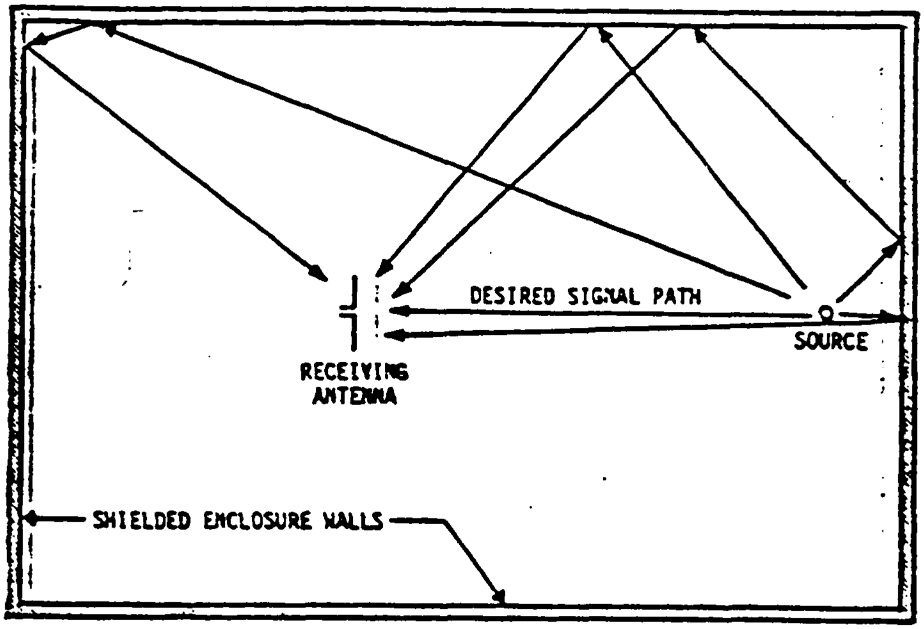


FIGURE 1: Multiple Signal Paths in Shielded Enclosure

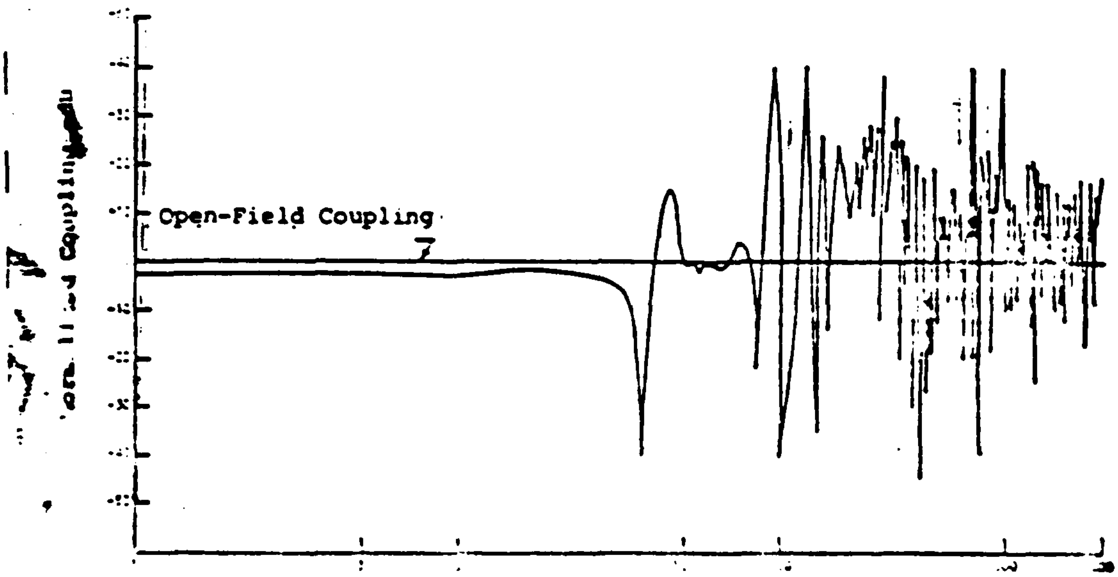
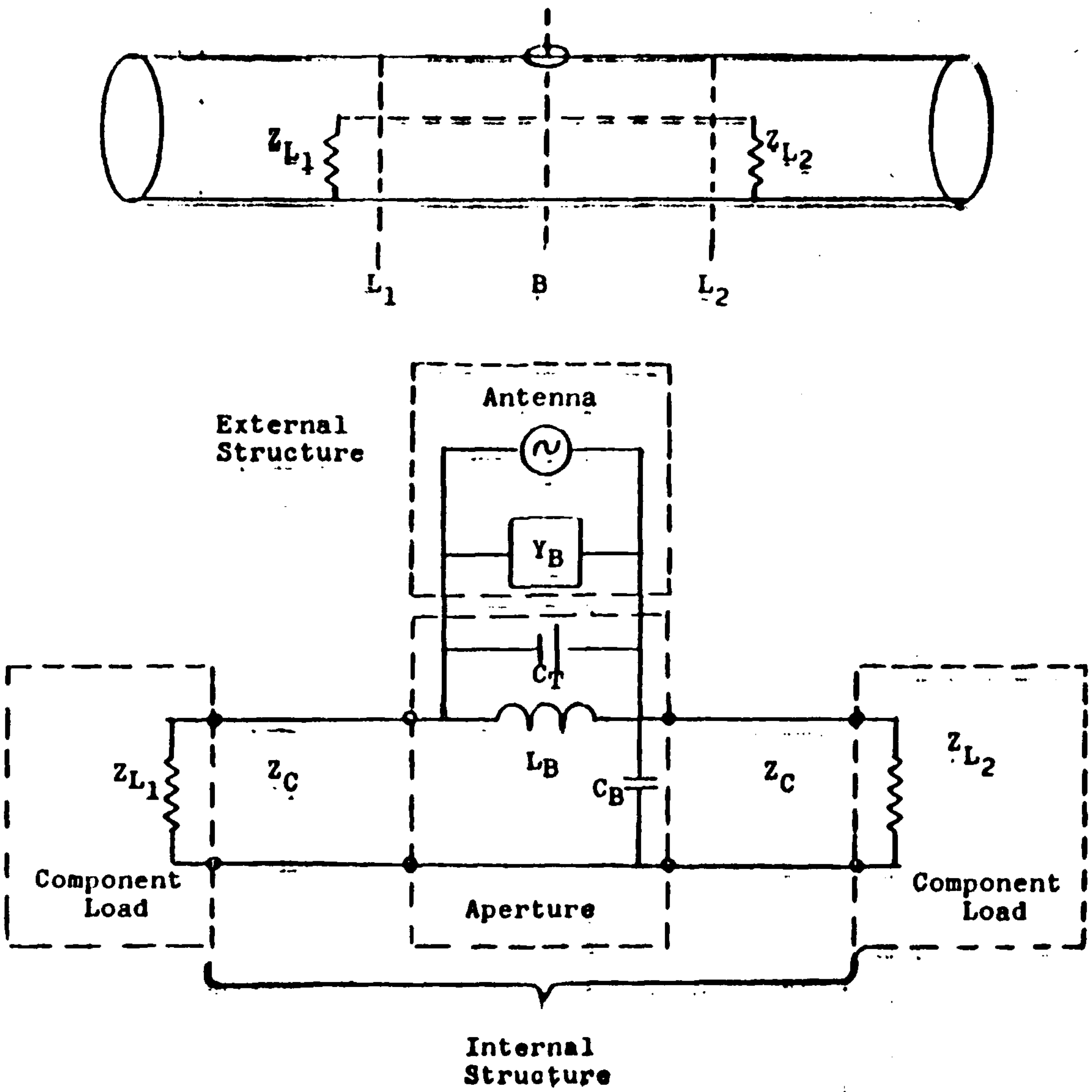
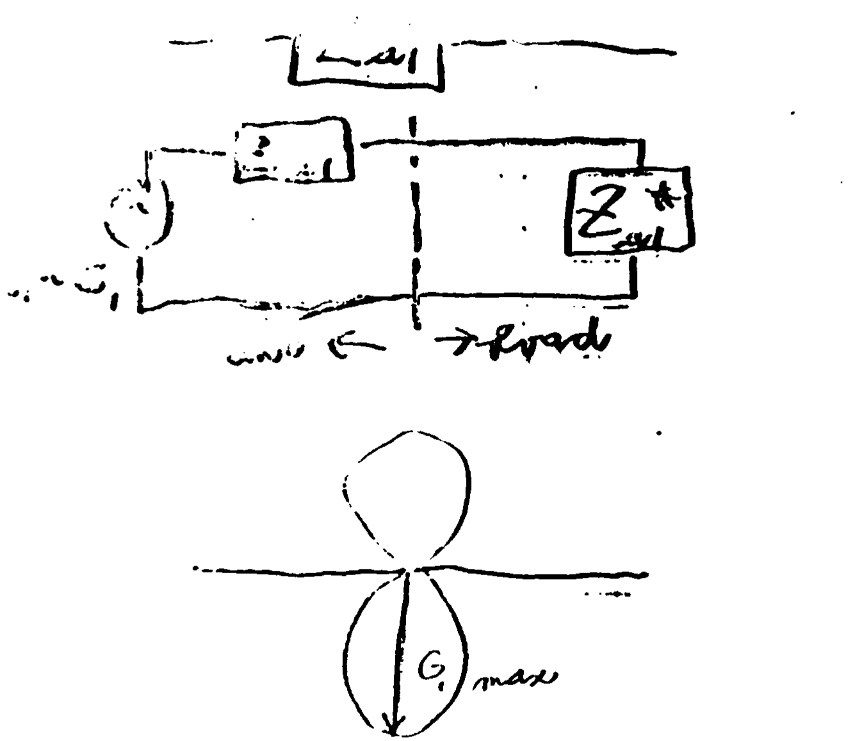


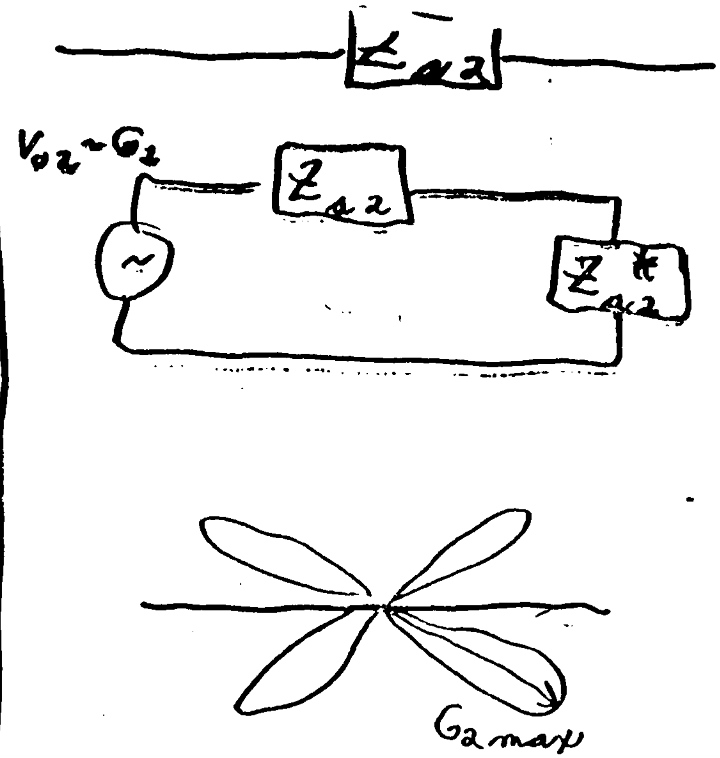
FIGURE 2: Coupling Between Antennas in Shielded Enclosure



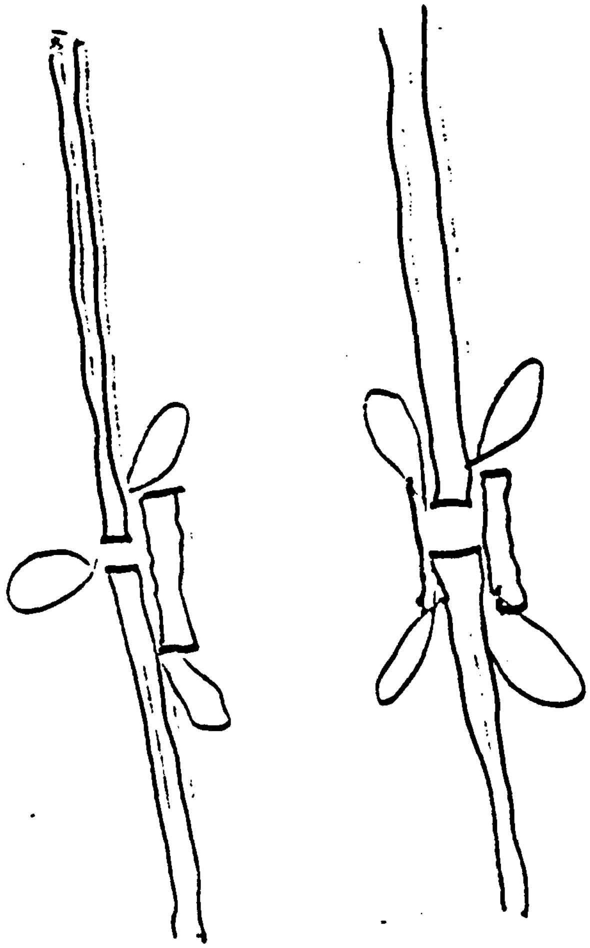
Z_{L_1}
Z_{L_2}
L_1
B
L_2
Antenna
External Structure
Y_B
C_T
L_B
C_B
Z_{L_1}
Z_C
Z_C
Z_{L_2}
Component Load
Aperture
Component Load
Internal Structure

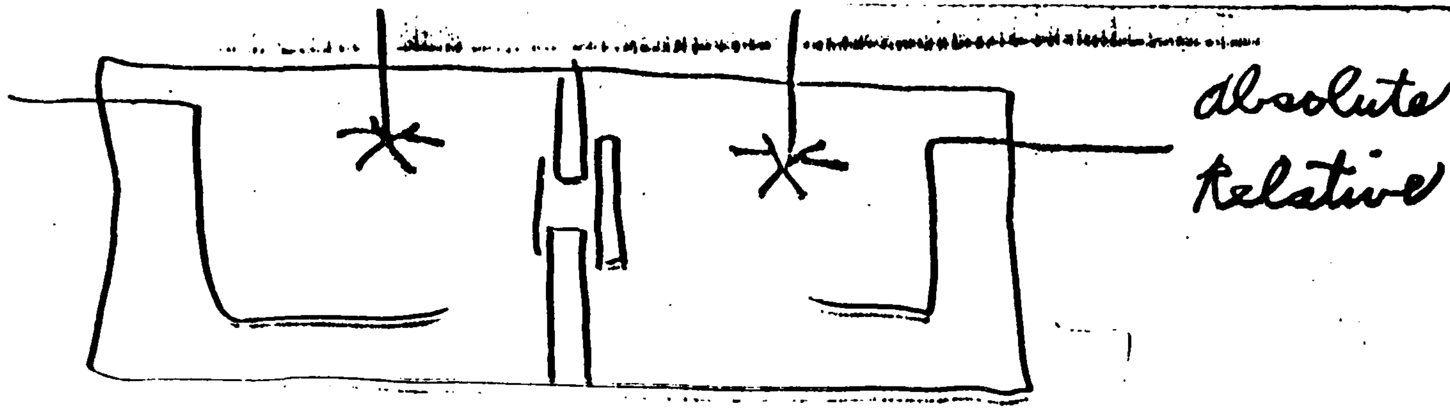
5

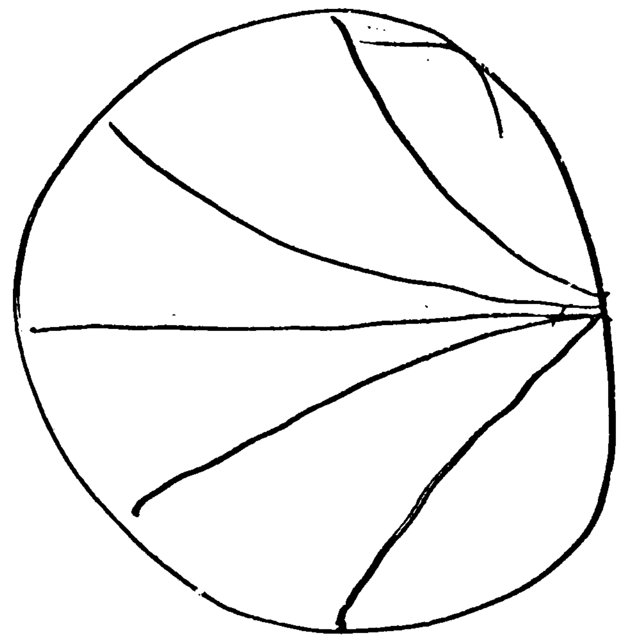


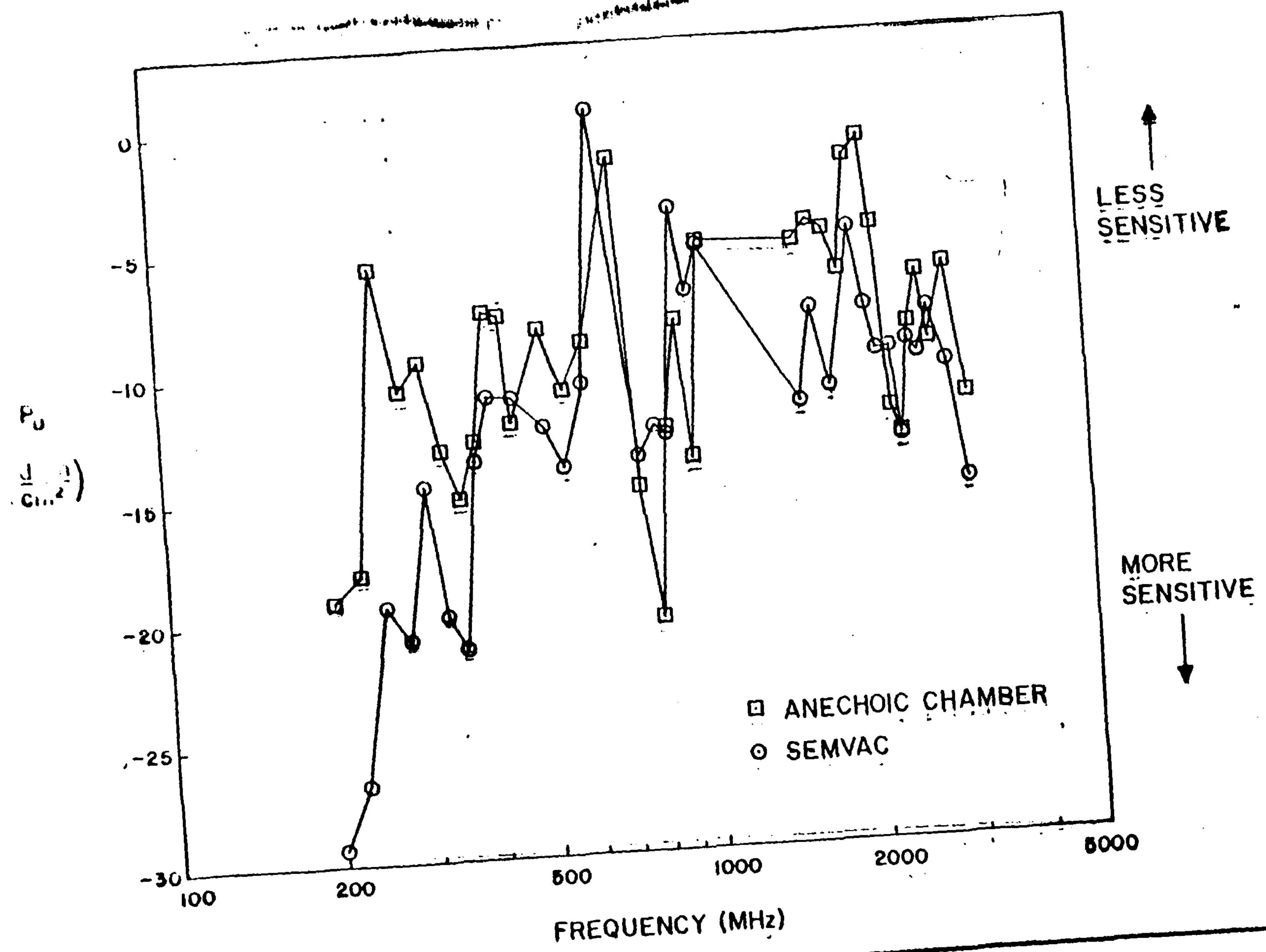


$$G_{1\,max} \neq G_{2\,max}$$
$$P_{1\,max} \neq P_{2\,max}$$
$$\overline{G}_1 \equiv \overline{G}_2$$
$$\overline{P}_1 \equiv \overline{P}_2$$




Absolute
Relative





LESS SENSITIVE
MORE SENSITIVE
ANECHOIC CHAMBER
SEMVAC
0
-5
-10
-15
-20
-25
-30
100
200
500
1000
2000
5000
FREQUENCY (MHz)

George Bechtold

NSWC/WO

OBJECTIVE: DETERMINE THE EMP SHIELDING EFFECTIVENESS OF A GRAPHITE/EPOXY COMPOSITE PANEL

APPROACH:

- TESTS WERE MADE IN A 20 KV/M FIELD PRODUCED BY THE NSWC SIMULATOR
- THE TEST OBJECT CONSISTED OF AN ALUMINUM CYLINDER WITH A COMPOSITE PANEL MOUNTED ON THE SURFACE
- THE INTERNAL H FIELD, E FIELD, AND THE CURRENT AND VOLTAGE ON AN INTERNALLY MOUNTED WIRE WERE MEASURED
- COMPARISONS WERE MADE WITH AN ALUMINUM PANEL AND WITH NO PANEL INSTALLED

[illegible] MEASUREMENTS OF COMPOSITE PANELS MOUNTED ON AN ALUMINUM CYLINDER ★

G. W. BECHTOLD

P. E. HUNTER

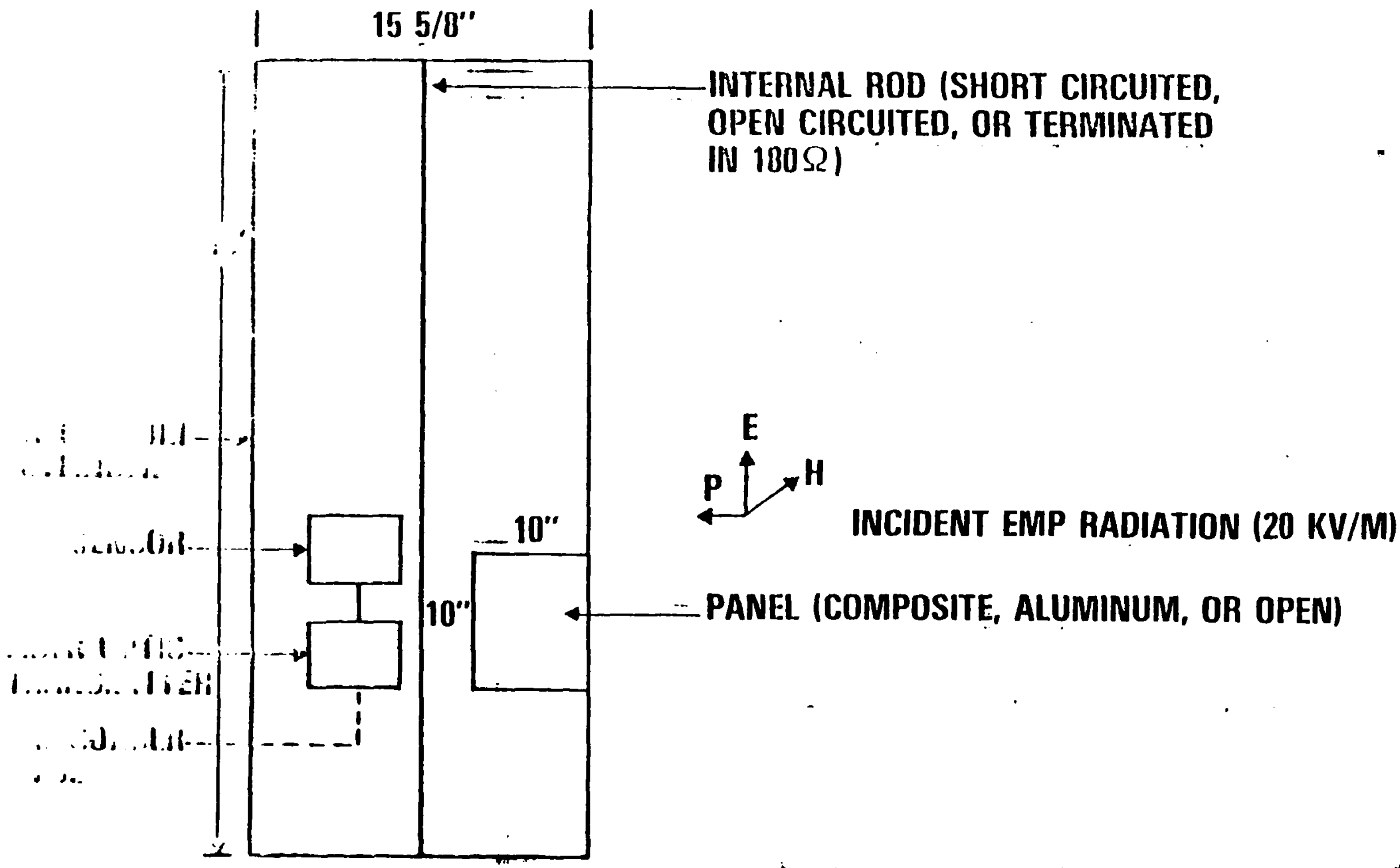
L. LIBELO

★ SPONSOR: NAVAL AIR SYSTEMS COMMAND

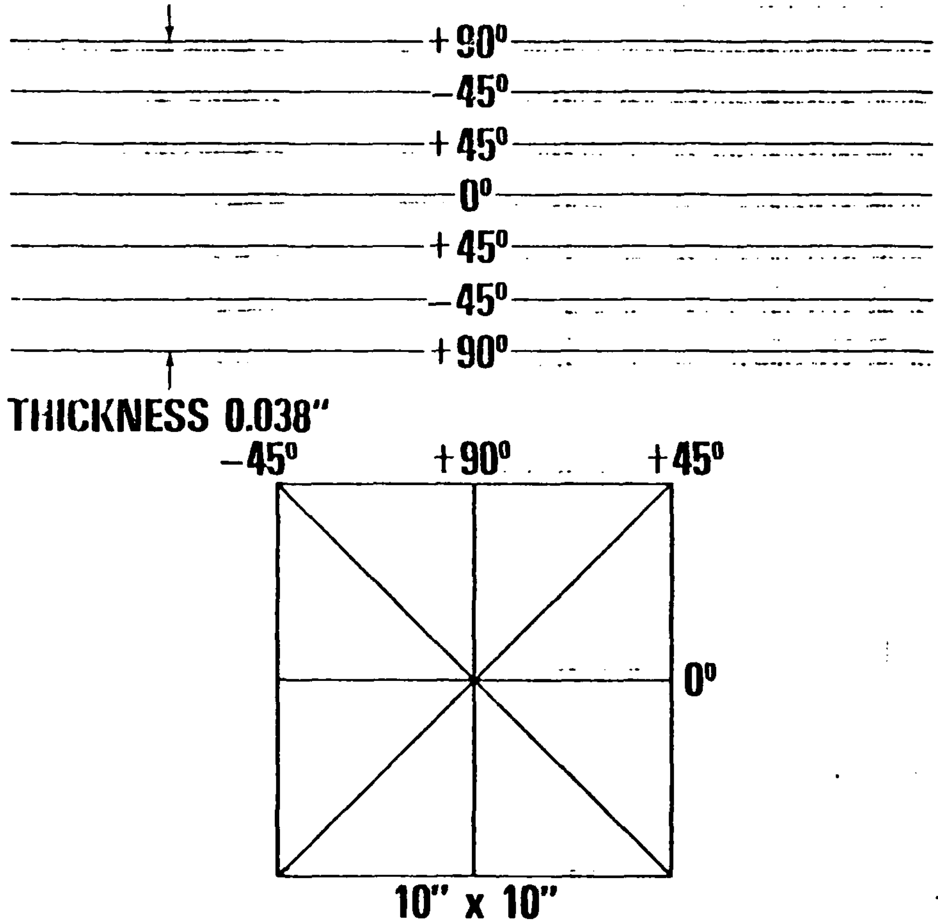
EMP MEASUREMENTS OF COMPOSITE PANELS MOUNTED ON AN ALUMINUM CYLINDER

- MEASUREMENTS WERE MADE IN THE NSWC EMP SIMULATOR
- RESPONSE OF ALUMINUM, COMPOSITE AND OPEN PANELS ARE COMPARED
- MEASUREMENT TECHNIQUES ARE DISCUSSED

SHIELDING EXPERIMENT

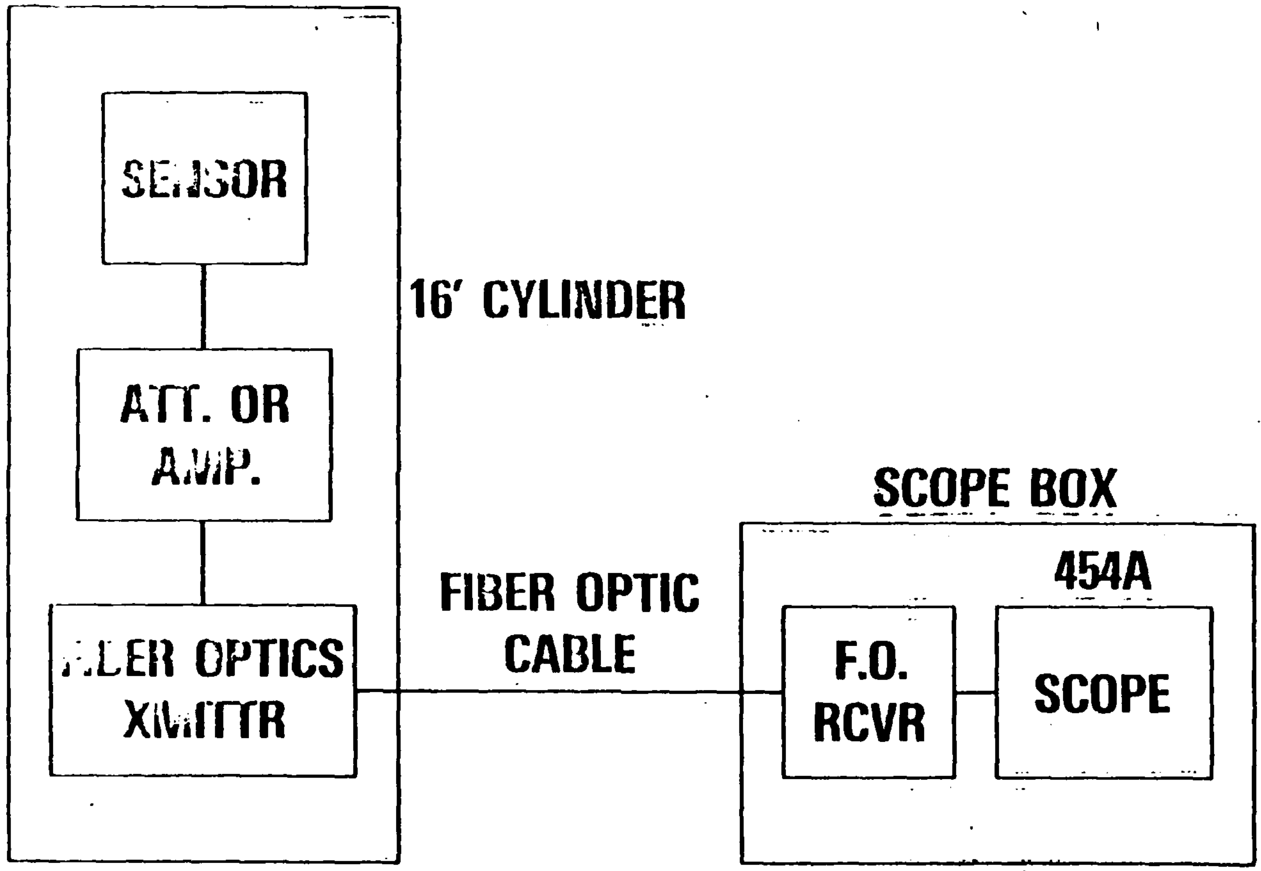


7 PLY COMPOSITE PANEL CONSTRUCTION

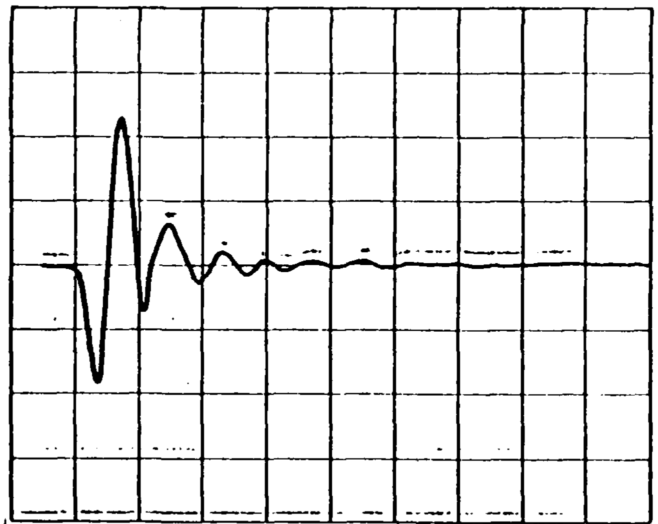


5

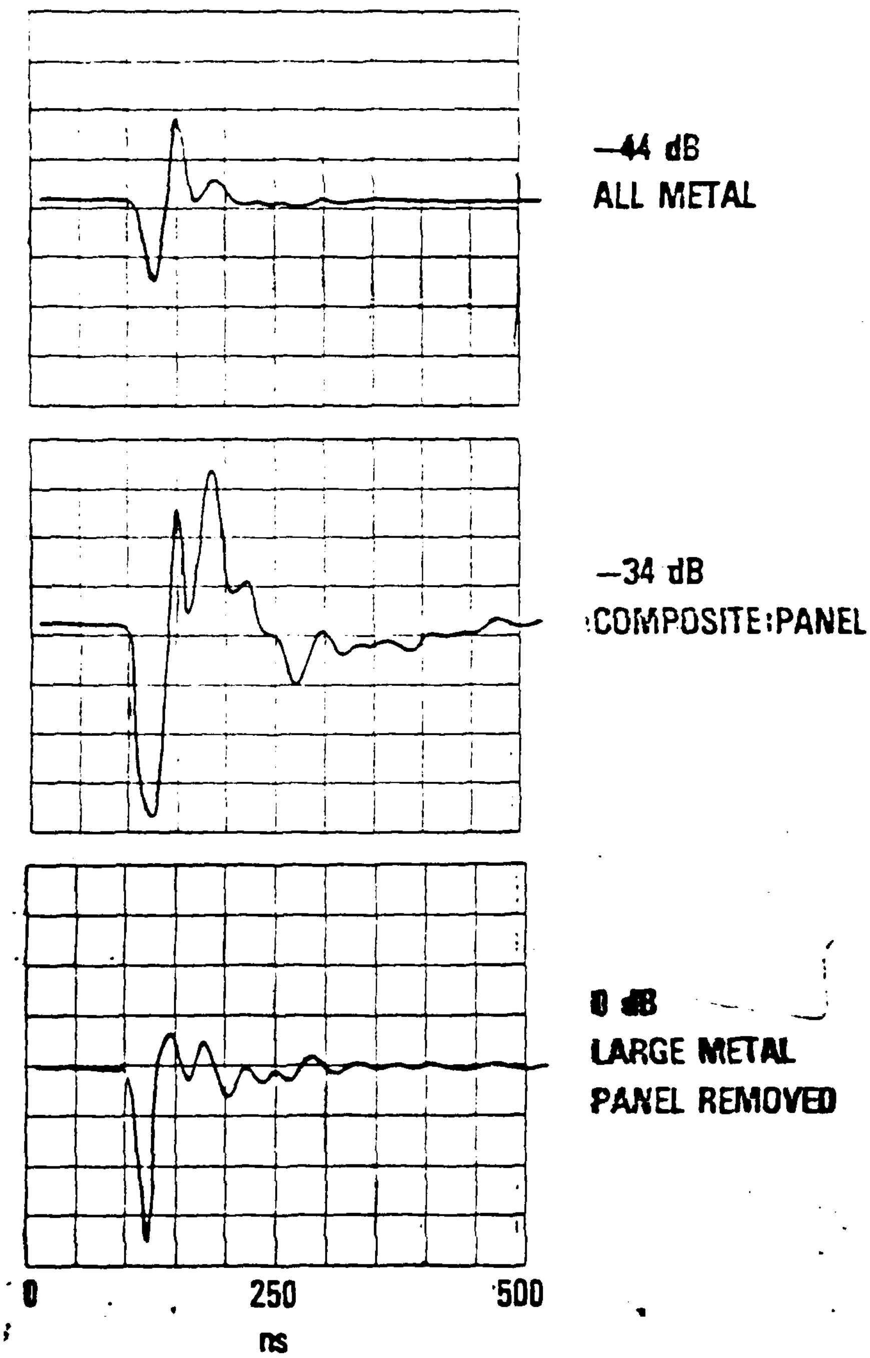
INSTRUMENTATION DIAGRAM



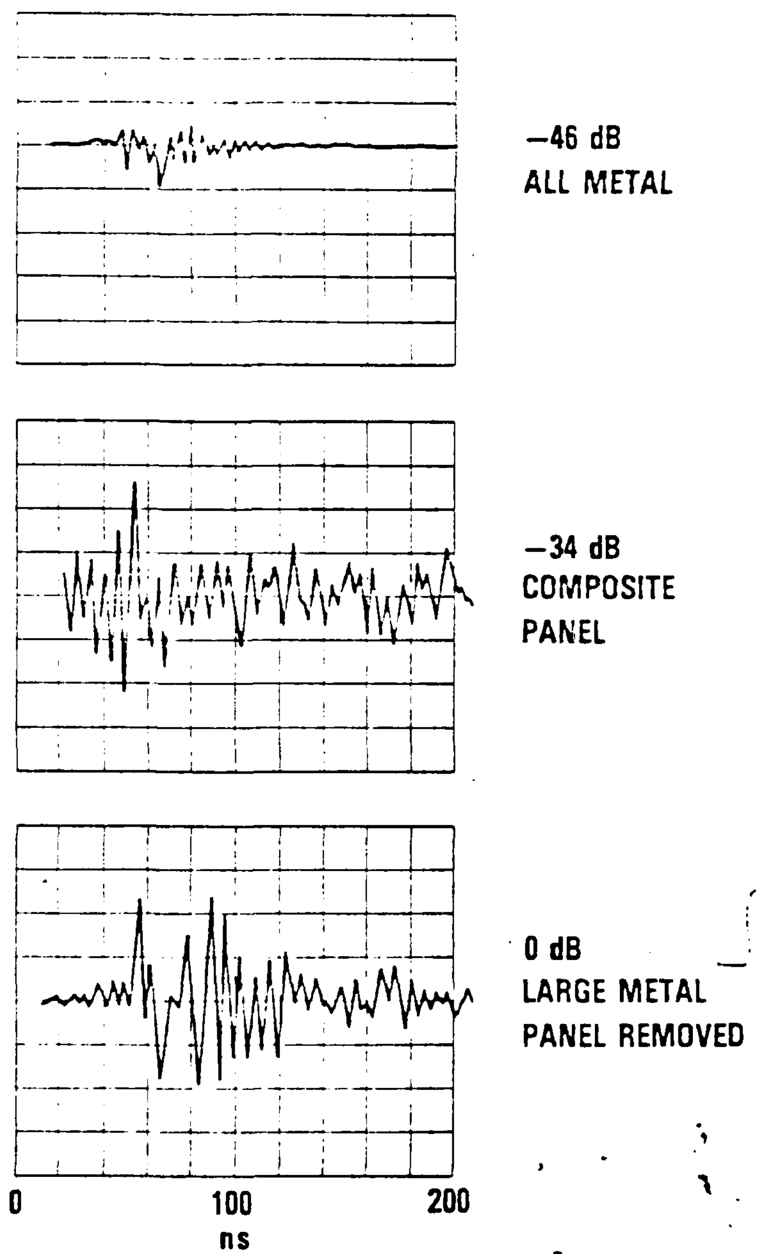
SKIN CURRENT AT THE CENTER OF THE CYLINDER



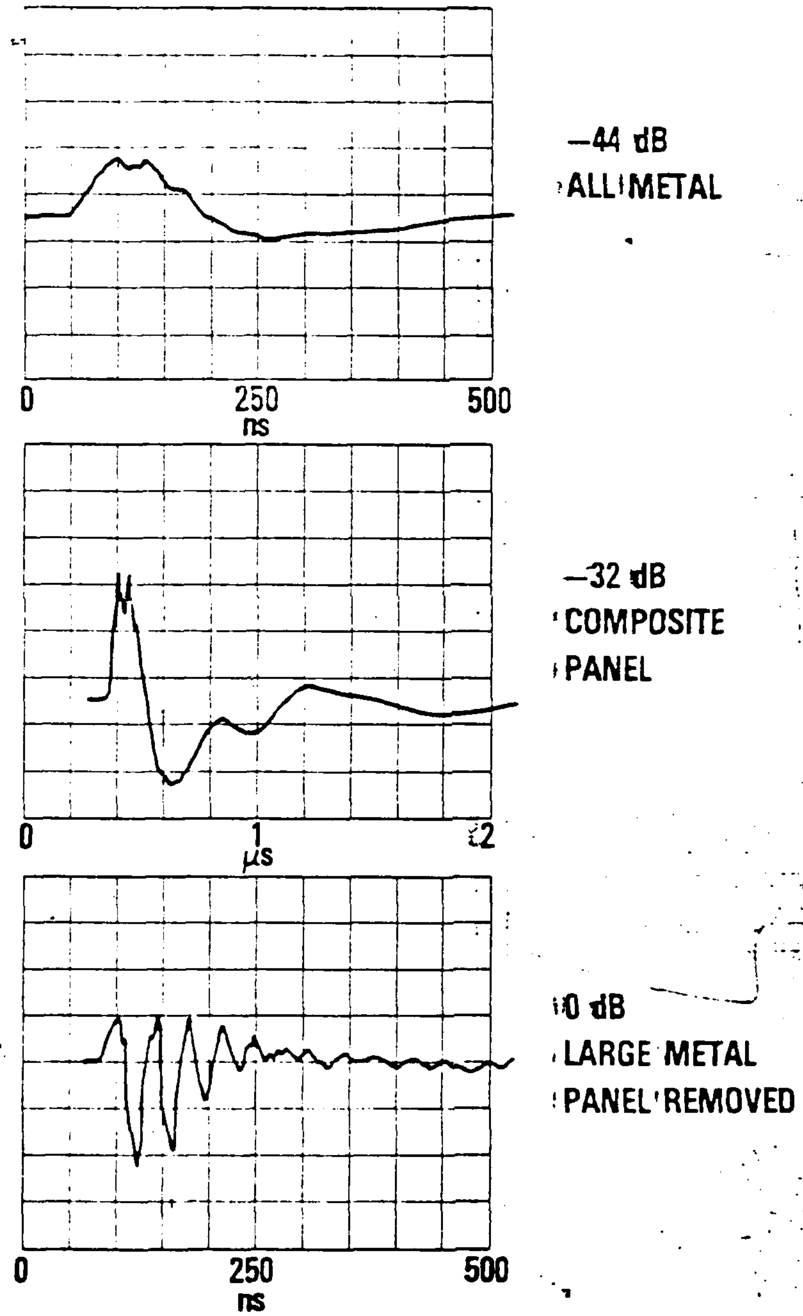
0.1 V/div
50 nS/div
CENTER OF
CYLINDER



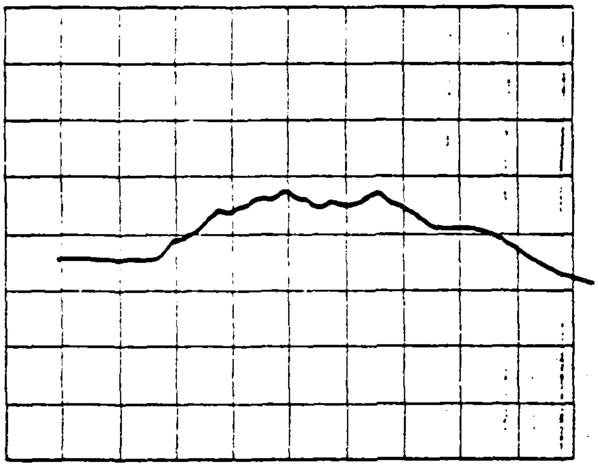
—44 dB
ALL METAL
—34 dB
COMPOSITE PANEL
0 dB
LARGE METAL
PANEL REMOVED
0
250
500
ns



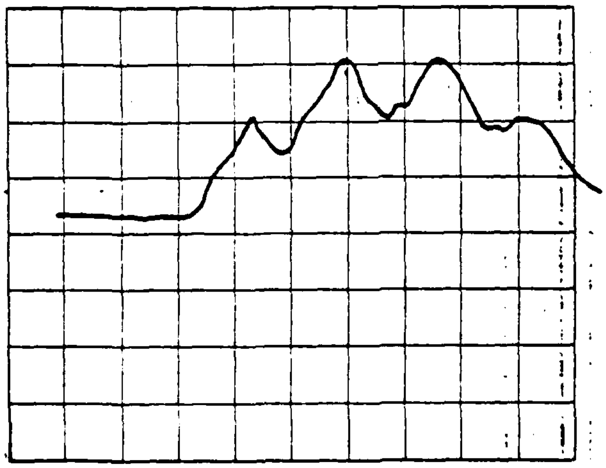
−46 dB
ALL METAL
−34 dB
COMPOSITE
PANEL
0 dB
LARGE METAL
PANEL REMOVED
0
100
200
ns


−44 dB
ALL METAL
0
250
ns
500
−32 dB
COMPOSITE
PANEL
0
1
μs
2
0 dB
LARGE METAL
PANEL REMOVED
0
250
ns
500

COMPOSITE VS. ALUMINUM TRANSMISSION (VERT POLARIZATION)



5 mV/div
20 nS/div
ALUMINUM
PANEL



10 mV/div
20 nS/div
COMPOSITE
PANEL

AD-A096 459 NAVAL AIR SYSTEMS COMMAND WASHINGTON DC F/G 11/4
REPORT OF COMPOSITE MATERIAL AND METAL COMPOSITES JOINT WORKSHO--ETC(U)
1978

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SUMMARY OF DATA
15 FOOT CYLINDER SHIELDING

	AL PANEL	COMPOSITE PANEL
H FIELD	44 dB	34 dB
E FIELD	40 dB	
CURRENT ON WIRE	46 dB	34 dB
VOLTAGE ON WIRE	44 dB	32 dB

NSWC

CONCLUSIONS

- COMPOSITE SHIELDING IS $\cong$12 dB WORSE THAN ALUMINUM AT EMP FREQUENCIES
- COMPOSITES EFFECT THE FREQUENCY CONTENT OF INTERNAL SIGNALS
- USING THE EXPERIMENTAL TECHNIQUES, COMPOSITE JOINTS CAN BE EVALUATED AT EMP FREQUENCIES

Gil Condon

General Electric

View Graphs Were Not Available

J. Roden

Syracuse Research Corporation

View Graphs Were Not Available

George Bechtold

NSWC/WO

Cliff Scouby

McDonnell Aircraft Corporation

View Graphs Were not Available

LMED

-8